ICAT 2003
December 3-5, Tokyo, JAPAN

See-through Sheet Visual Display for Haptic Device Using Flexible Sheet

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Abstract

A haptic device using flexible sheet such as rubber has already been proposed. Controlling the bias tension of the sheet, the device varies compliance of the sheet in the normal direction; users can feel compliance of various virtual objects if they touch the sheet. This device is integrated into a visual and haptic display. The haptic device uses transparent flexible sheet, and a liquid crystal display is placed under the sheet. If users touch the sheet, they feel compliance of virtual objects while seeing both their own hands directly and the image of the deformed objects through the sheet. In the present paper, this see-through sheet visual display is developed and evaluated.

Key words: Haptic Device, Flexible Sheet, Variable Compliance, See-through Sheet Display, Flexible Object

1. Introduction

For the purpose of obtaining good reality in virtual reality applications, it is important to display haptic sense when users touch virtual objects; the devices displaying virtual haptic sense are called ``haptic devices'' or ``haptic displays''[1-4]. One of the applications of haptic devices in medical field will be a master device of tele-treatment. A doctor operates a slave manipulator in a distant place using the master device, and the manipulator treats a remote patient. If the manipulator touches the body of the patient, the haptic sense measured by the manipulator is fed back to the doctor through the master device. As a result, the doctor feels as if he directly touches the patient. Another application in medical field will be a training simulator of surgery. A trainee experiences virtual surgery; he feels simulated haptic sense in surgery through the haptic device. In both cases, it is necessary that doctors can feel as if they treat real patients directly: they can feel like touching patients' bodies directly with their hands or fingers, and the haptic devices do not restrict the motion of the hands or fingers. In these applications, displayed objects are human bodies and organs, which are soft and flexible.

In the previous study[5], we proposed a haptic device using flexible sheet such as rubber; this device aims at displaying haptic sense of soft objects such as human bodies and organs. Controlling the bias tension of the sheet, the device varies compliance of the sheet in the normal direction; users can feel compliance of various virtual objects if they touch the sheet. This device enables the users to feel as if they touch the virtual objects directly with their hands or fingers. Because the users do not wear the device, the motion of their hands or fingers is not restricted.

For the purpose of giving higher reality using this device, not only haptic feedback but also visual feedback to users are important. As described above, the device enables the users to feel as if they touch virtual objects directly with their hands. Accordingly, if they can directly see their own hands touching the virtual objects, the device can provide good reality and operability to the users.

Based on this idea, we intend to integrate this device into a visual and haptic display. The haptic device uses transparent flexible sheet, and a liquid crystal display (LCD) is placed under the sheet. First, a user feels compliance of a virtual object by touching the sheet. At the same time, the position and the deformation of the touched point on the sheet are measured with two cameras. Second, the virtual image of the deformed object is calculated from the measured deformation and displayed on the LCD. Then the user sees the image through the transparent sheet. In this way, if the user touches the sheet, he feels compliance of the virtual object while seeing both his own hand directly and the image of the deformed object through the sheet.

In the present paper, this see-through sheet visual display is developed. We measure the static errors between the touched point on the sheet and the image displayed on the LCD; the errors are within 6[mm]. The results of sensational evaluation by human subjects show that this system is available: the subjects feel like touching and seeing virtual objects.

2. Haptic Device Using Flexible Sheet

Fig. 1 illustrates the principle of displaying variable compliance by the haptic deice using flexible sheet, which we already proposed[5]. Controlling the bias tension of the sheet, the device varies compliance of the sheet in the normal direction: the tightly pulled sheet feels hard, and the loosen sheet feels soft. We developed a prototype haptic device using a square rubber sheet shown in **Fig. 2**. The sheet is 150[mm] × 150[mm] square and 1[mm] in thickness. This device controls the bias tension of the sheet by pulling its four corners with four motors.

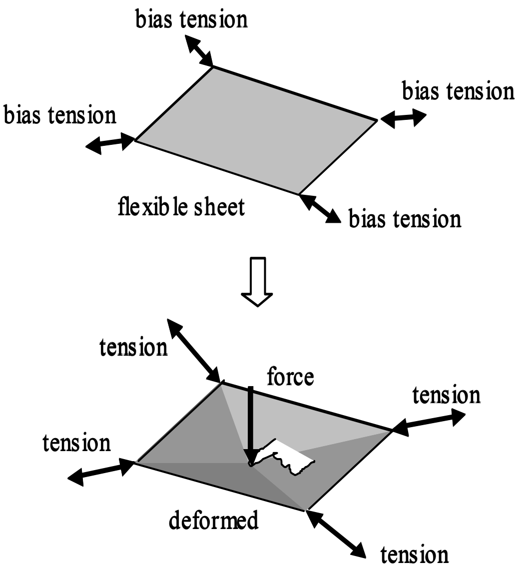


Figure 1: Principle of haptic device using flexible sheet[5]

We have measured the fundamental characteristics of the prototype haptic device: force-displacement curve and dynamic response. The force-displacement curve is the relationship between the normal force applied to the center of the sheet and the displacement at the point; the tangential angle of this curve represents compliance. The results show that the developed device can generate different compliance by changing the bias tension[5]. This device can vary the compliance in response to 5 [Hz] sinusoidal change of the bias tension[6]. Furthermore, the compliance of human palm have been measured and simulated by the device[7].

3. Visual and Haptic Display using Flexible Sheet

3.1 System Configuration

If users can feel like touching virtual objects directly with their hands and can directly see their own hands touching the virtual objects, such device can provide good reality and operability to the users. For this purpose, we propose a visual and haptic display using flexible sheet. **Fig. 3** shows the system configuration of this system. The haptic device uses transparent flexible sheet, and an LCD is placed under the sheet. Hence users see the images of virtual objects through the sheet. If the user touches the sheet, he feels compliance of the virtual object, while seeing both his own hand directly and the image of the deformed object through the sheet.

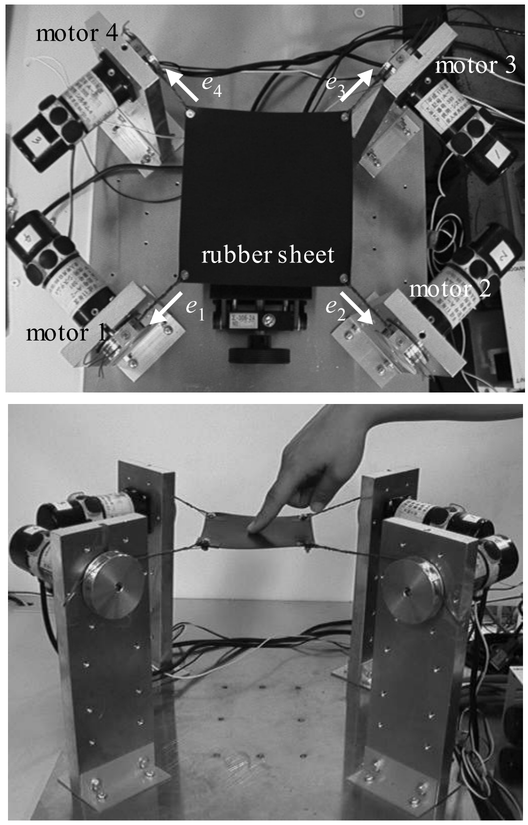


Figure 2: Prototype haptic device using flexible sheet[5]

This system consists of 3 subsystems: object modeling system, haptic display system and visual display system.

1) Object modeling system

   This subsystem manages the model of a virtual object: its material data including compliance, size, shape and so on. It receives the position (*x,y*) and the deformation *z* of the touched point on the sheet from the visual display system, and generates the 3D shape model of the deformed object. Then this model is sent to the visual display system.

2) Haptic display system

   This subsystem receives the compliance data of the virtual object from the object modeling system, and varies compliance of the sheet by controlling the bias tension of the sheet.

3) Visual display system

   This subsystem measures the position (*x,y*) and the deformation *z* of the touched point on the sheet with two cameras. The measured (*x,y,z*) is sent to the object modeling system, and the 3D shape model of the deformed object is returned. The 2D image of this model is displayed on the LCD.

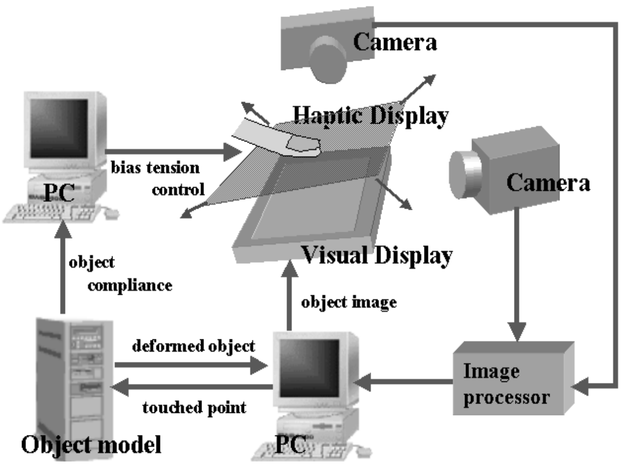


Figure 3: System configuration of visual and haptic display

3.2 Features of System

First, the futures of the haptic device using flexible sheet are summarized.

1) This device is contact-type, which is directly touched by user's hand or fingers. Thus it enables users to feel as if they touch virtual objects directly with their hands or fingers.

2) Because the users do not wear the device, the motion of their hands or fingers is not restricted.

3) The device is a passive system: it does not apply force to the users but varies sheet compliance. Hence the device is safe if the users touch it for obtaining virtual haptic sense.

4) The users can move their fingers on the sheet; they can stroke the virtual objects.

5) This device is difficult to display hard or rigid objects because the sheet is soft. It is suitable for displaying haptic sense of soft objects such as human bodies and organs.

In addition, the proposed visual and haptic display has the following features:

1) The users directly see their own hands touching touch the sheet; that provides good reality and operability to the users.

2) The users can feel like touching the virtual object directly by their own hands, because the actual image of their hands and the virtual image of the object are naturally mixed.

3) If the sheet coordinate system coincides with the LCD coordinate system in advance, the actual image and the virtual image don't need to be aligned in use.

The above-mentioned features are effective for medical applications described in Section 1. **Fig. 4** shows an example where this device is applied to a training simulator of palpation. The virtual patient is displayed to the doctor, and the doctor touches the haptic device simulating the compliance of the patient. As a result, the doctor feels as if he directly touches the virtual patient.

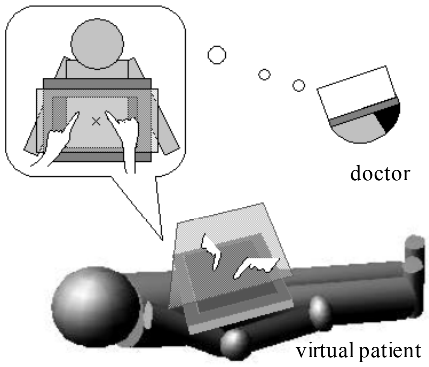


Figure 4: Example of medical application of visual and haptic display; training simulator of palpation

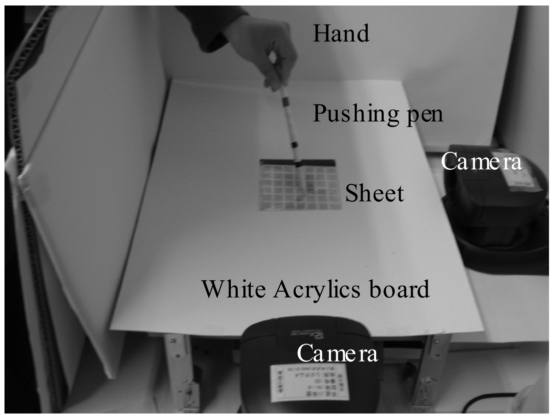


Figure 5: Overview of developed see-through sheet visual display

4. See-through Sheet Visual Display

4.1 Configuration of Display

In this paper, we have developed a visual display system, a subsystem of the visual and haptic display;

here we call it ``see-through sheet visual display''. **Fig. 5** shows its overview. The transparent flexible sheet is 100[mm]×100[mm] square and 1[mm] in thickness; it is made of polyurethane rubber. Bias tension is constant. A 15-inch LCD is placed under the sheet. The outsides of the sheet are covered with a white acrylics board, for preventing users from seeing unnecessary views. The distance between the LCD and the sheet is 20[mm]. Two CCD cameras (EVI-E30 made by SONY) are arranged as shown in Fig. 5. The users push the sheet with a pushing pen with 2 markers.

The position (x,y) and the deformation z of the touched point on the sheet is obtained by extracting these 2 markers from each camera image with image processing board (IP5000 made by HITATI).

4.2 Model of Flexible Object

In this paper, we aim at developing and evaluating the see-through sheet visual display. Hence we use a simple model to calculate the deformation of the virtual object. The object is a rectangular parallelepiped: $w \times w$ square and t in thickness. The object is placed so that its square surface may be parallel to the transparent sheet. When the point (x,y) on this surface is pushed and the deformation (normal displacement) at this point is z, the normal displacement z_r of the point (x_r,y_r) on this surface is given by

$$z_r = z\cos(\pi r / w),\ \ r = ((x_r - x)^2 + (y_r - y)^2)^{1/2} \qquad (1)$$

The pushed point gives maximum displacement, and the displacement changes in sinusoidal wave in proportion to a distance from the pushed point.

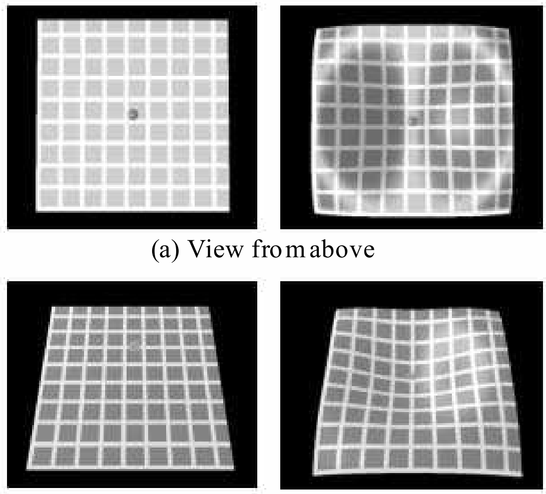
Using this model, the 3D shape of the deformed object is calculated from the measured deformation. Then the virtual 2D image of the deformed object created by *OpenGL* is displayed on the LCD. Some examples of the virtual images are show in **Fig. 6**.

5. Static Errors at Touched Points

5.1 Experiment

It is important for the proposed see-through sheet visual display that the touched point on the sheet overlaps with the touched point on the virtual image of the object displayed on the LCD. We measure the static errors between these points seen from the viewpoint of users.

Users push the sheet with the pushing pen in the normal direction as shown in **Fig. 7**. They see the developed display from 2 directions: from above and from obliquely above. A digital camera is placed at these viewpoints of users and takes the pictures of pushing the sheet with the pen. The errors between the position of the tip of the pen and the most dented point of the virtual image of the object in these pictures are measured.



(a) View from above

(b) View from obliquely above

Figure 6: Virtual images of deformed object

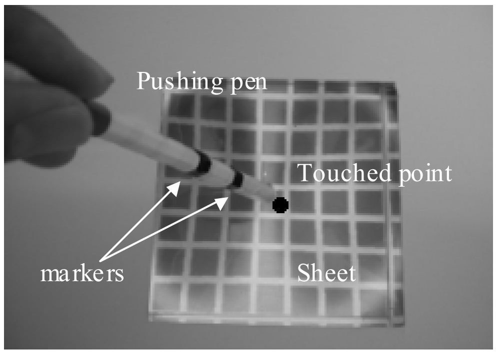


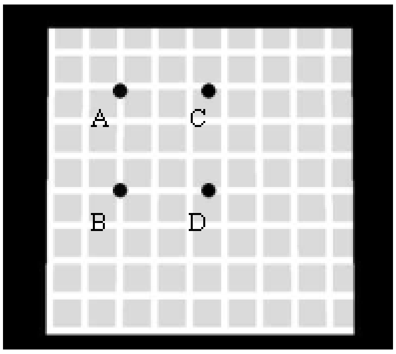
Figure 7: Experiment of static errors at touched points

Before the experiments, the virtual image of the object is displayed on the LCD so that the center of the sheet may overlap with the center of the virtual image seen from the viewpoints of users.

5.2 Experimental Result

Fig. 8 shows 4 touched points measured in the experiments; the coordinates of these points are represented in OpenGL coordinate system. **Table 1** summarizes the experimental result: the errors between the touched point on the sheet and the touched point on the virtual image of the object. These errors are measured on the pictures taken from the viewpoints of users and converted into the distance on the sheet.

The errors are within 2[mm] when seen from above and within 6[mm] seen from obliquely above; the errors seen from obliquely above is larger than that from above. In both cases, the touched points further from the center of the sheet give larger errors. This is because the deformation has much effect on the errors.



A: (-10, 10)
B: (-10, 0)
C: (0, 10)
D: (0, 0)

Figure 8: Touched points in experiment

Table 1: Experiment result of static errors at touched points

Touched point	View from above	View from obliquely above
A	2.07[mm]	5.51[mm]
B	0.00[mm]	1.63[mm]
C	0.00[mm]	2.34[mm]
D	0.00[mm]	0.00[mm]

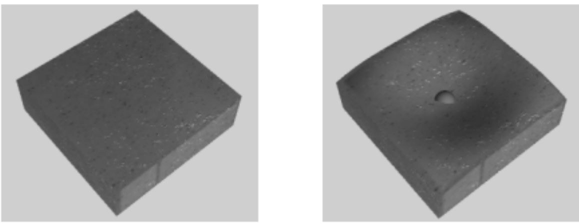


Figure 9: Virtual soft object with texture of ``*konnyaku*''

6. Sensational Evaluation by Human Subjects

6.1 Experiment

We evaluated whether human subjects feel as if they are seeing and touching virtual objects directly using this see-through sheet visual display.

A virtual soft object of rectangular parallelepiped with texture of "*konnyaku*" is used; **Fig. 9** shows the virtual images of this object. As shown in **Fig. 10**, five men in twenties test this display in two ways: pushing the sheet with the pushing pen in the normal direction, and stroking the surface of the sheet with the pen at the speed when one circle of 20[mm] radius is drawn per 3[s]. The viewpoint of human subjects is fixed to the point obliquely above from the sheet. After the trial, they evaluate whether they feels like seeing and touching the virtual object directly on a scale of one (``feel like so very mush'') to five (``never feel like so'').

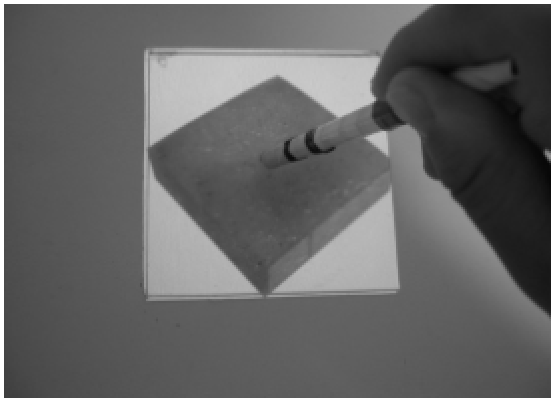


Figure 10: Experiment of sensational evaluation by human subjects

Table 2: Experiment result of sensational evaluation by human subjects

Question: ``Do you feel like seeing and touching virtual object directly?''

Evaluation	Pushing	Stroking
1: feel like so very much	1	0
2: almost feel like so	4	4
3: either way	0	1
4: not feel like so much	0	0
5: never feel like so	0	0

(Number of subjects)

6.2 Experimental Result

Table 2 summarizes the experimental result. Every human subject almost feels like seeing and touching the virtual soft object directly. One subject says that the touched point sometimes looks like blinking. This is because the image processing fails to extract the markers on the pushing pen. Another subject says that the touched point on the virtual image moves slower than the touched point on the sheet if the pen moves more quickly. This is due to the delay by the image processing, calculating the 3D shape model of the deformed object and displaying its 2D image on the LCD.

7. Conclusion

A haptic device using flexible sheet such as rubber has already been proposed; this device aims at displaying haptic sense of soft objects such as human bodies and organs. Controlling the bias tension of the sheet, the device varies compliance of the sheet in the normal direction; users can feel compliance of various virtual objects if they touch the sheet. In this paper we intend to integrate this device into a visual and haptic display. The haptic device uses transparent flexible sheet, and an LCD is placed under the sheet. First, a user feels compliance of a virtual object by touching the sheet. At the same time, the position and the deformation of the touched point on the sheet are measured with two cameras. Second, the virtual image of the deformed object is calculated from the measured deformation and displayed on the LCD. Then the user sees the image through the transparent sheet. In this way, if the user touches the sheet, he feels compliance of the virtual object while seeing both his own hand directly and the image of the deformed object through the sheet.

This see-through sheet visual display is developed. We measure the static errors between the touched point on the sheet and the image displayed on the LCD; the errors are within 6[mm]. The results of sensational evaluation by human subjects show that this system is available: the subjects feel like touching and seeing virtual objects.

In the future work, the see-through sheet visual display will be improved so that 3D images of virtual objects can be displayed and that users can touch the sheet with their fingers and hands directly. We will develop a visual and haptic display by integrating the haptic device using flexible sheet and the see-through sheet visual display. Furthermore, we will apply the display to medical field as shown in Fig. 4.

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