

A Non-Rigid Force Sense Presentation Method for a Finger-Mounted Type Haptic Device

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ABSTRACT

Recently, several researches of haptic devices have been conducted. Haptic devices provide users with a sense of touching virtual objects such as Computer Graphics (CG) by force feedback. Since they provide force feedback from a single point on an object surface where users touched, users touch it by point contact. However, they cannot provide a sense such as humans touching an object with a finger pad because humans do not touch by point contact but surface contact. I focused on this characteristic and developed surface contact haptic device. To touch a CG object in surface contact, we use a plane interface. It provides force feedback to the normal direction by being approximated to tangent plane on a CG object surface where users touched and the sense of grabbing it. In the evaluation experiments, ten users evaluated this haptic device. From results, we see that users could feel a non-rigid object by surface contact.

KEYWORDS

Haptic device, non-rigid object, plane interface, force feedback, surface contact

1 INTRODUCTION

1.1 Back Ground

In recent years, researches of human interface using Augmented Reality (AR) have been conducted. In order to touch a CG object that is drawn by AR, a haptic device has been developed. By using a haptic device, users can perceive touching a CG object by processing a force feedback. Therefore, the haptic device has been expected to be applied to applications such as virtual a surgery simulation system and a virtual experience system.

As conventional haptic devices, there are Falcon[1], PHANToM[2] and Dexmo[3]. These haptic devices have been developed as a point contact haptic device. By using this type

haptic device, users can perceive touching a CG object because users are provided with a force feedback from a single point at the CG object surface where they touched. However, when a human is touching an object, there is a characteristic that a human perceives the shape by feeling the force sense from the contact surface in reality. We focused on this characteristic. In addition, we have developed a finger mounted type haptic device using a plane approximated tangent plane [4] that is shown in Figure1.

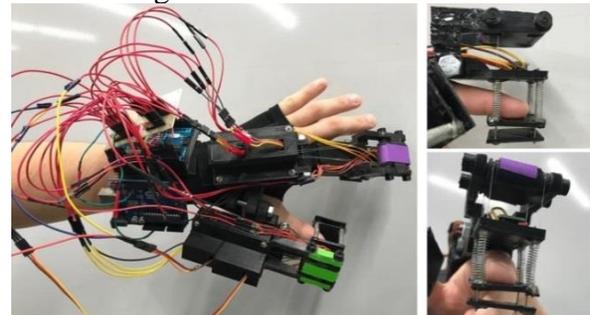


Figure 1: finger-mounted type haptic device

Figure2 shows the outline of the developed haptic device. The haptic device uses a plane interface having four movable points. Figure2-(a) shows the initial state. In this state, the user is not touching a CG object. Figure2-(b) shows the operating state. In this state, the user is touching a CG object. The plane interface provides force feedback with a finger pad.

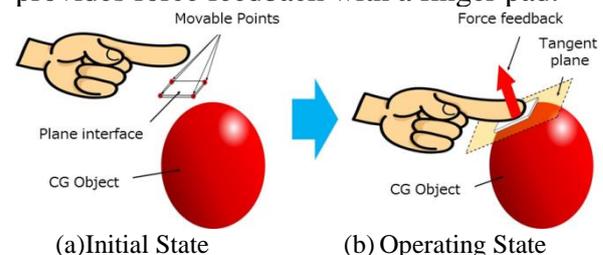


Figure 2: Outline of the proposed haptic device

1.2 The Purpose of This Research

This device represents only a feeling of rigid objects. However, in the real world, we think that there are many opportunities to touch not only rigid objects but also soft objects, that is non-rigid objects. In this research, we propose and implement a haptic presentation method for a non-rigid object as the contact object.

2 OUR APPROACH

In the haptic device developed in this research, motor are connected to each movable point of the plane interface to express the feeling that it is in contact to a non-rigid object in order to consider the up and down movements of the plane interface. In the haptic presentation method, a change in haptic force as it is pushed after touching an object is expressed based on a spring model that we propose.

3 THE PROPOSED SYSTEM

3.1 Hardware Construction

Figure3 shows the hardware construction of the proposed haptic device. In this device, a model designed using DesignSpark shown in Figure4 was created with a 3D printer. This haptic device is glove type to touch a CG object and composed of Arduino Uno and four servo motors that are shown in Figure 5 and 6, respectively, four springs and a plane interface for each finger. Figure 7 shows the appearance of the proposed haptic device.

Place Arduino Uno on the back of the hand as shown in Figure3. As shown in Figure8, each spring is bonded to each movable point. Furthermore, each motor is controlled by Arduino Uno, and the wires connected to the motor move the movable interface by moving each movable point up and down.

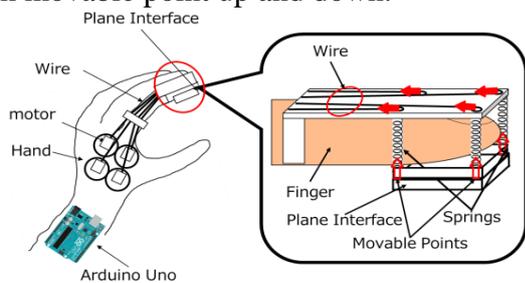


Figure 3: proposed haptic device

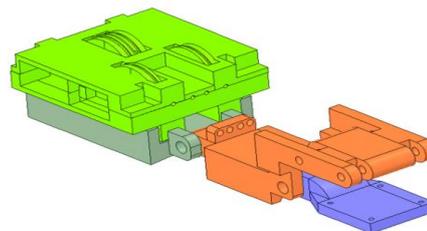


Figure 4: Design drawing of haptic device by DesignSpark



Figure 5: Arduino Uno



Figure 6: Servo motor (SG90)

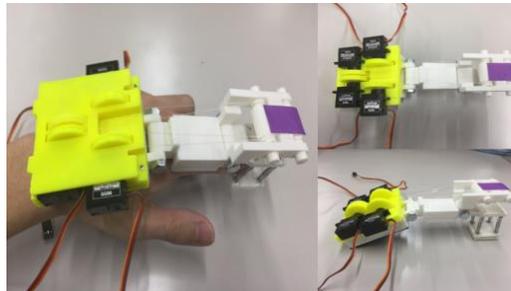


Figure 7: Appearance of the haptic device

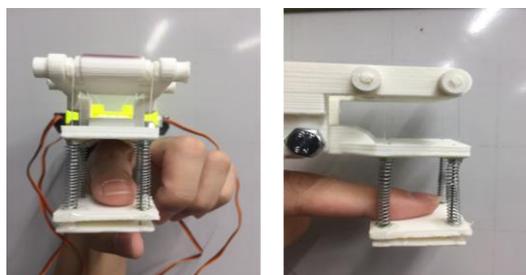


Figure 8: Fingertip part

3.2 System Overview

In this system, users touch a CG object in the display with the proposed haptic device and feel force feedback. Figure 9 shows system overview. I use PC, display, Creative Senz3D and the proposed haptic device. Users wear the

proposed haptic device and touch a CG object. Figure 10 shows Creative Senz3D. Creative Senz3D is RGB-D camera whose range of depth sensor is 0.15-1[m]. I use it to draw CG objects and to detect 3-dementional finger position from it.

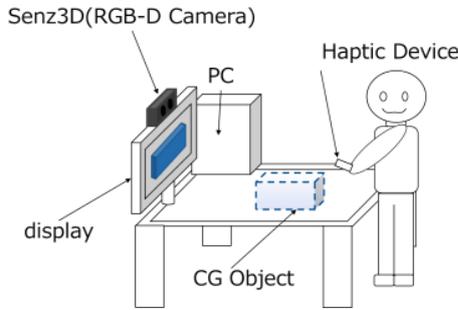


Figure 9: System Overview



Figure 10: Sens3D (RGB-D Camera)

3.3 The System Flowchart

Figure 11 shows the system flowchart. This system draws a CG object on the desk and calculates a finger position. When the fingertip touches the CG object, this system calculates motor rotation angles and sends these angles to Arduino Uno by serial communication. Arduino Uno controls motors and moves the plane interface. A plane interface provides a fingertip with force feedback so users feel touching a CG object. The followings are the explanation of the processing in this system.

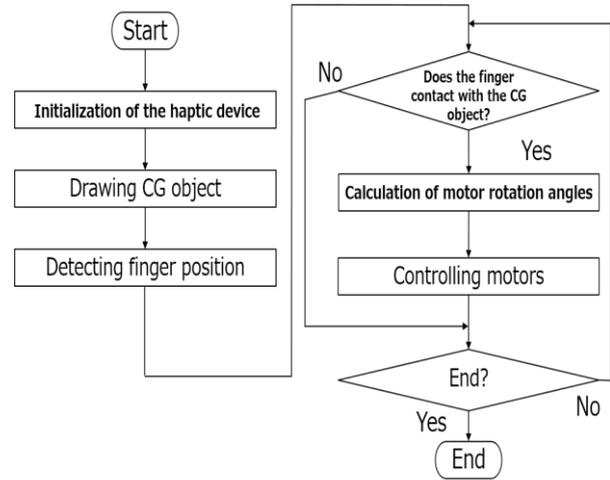


Figure 11: Flowchart

(1) Initialization of the haptic device

Arduino Uno controls motors to make a plane interface initial position.

(2) Drawing a CG object

In the drawing AR object, this system draws a CG object on a desk. To draw a CG object, this system detects a plane by using depth information from Sens3D. Figure12 is the image including a plane (desk). Users set a point as an origin on the plane using mouse cursor. This system sets other two points on the plane and calculates vectors $A = (a_x, a_y, a_z)$ and $B = (b_x, b_y, b_z)$ from the set point to other points. By using these vectors, this system calculates the normal vector from arbitrary points to other points are calculated. Using these vectors, normal vectors $N = (N_x, N_y, N_z)$ from outer product of vectors.

$$B \times A = \begin{pmatrix} b_y a_z - b_z a_y \\ b_z a_x - b_x a_z \\ b_x a_y - b_y a_x \end{pmatrix} = \begin{pmatrix} N_x \\ N_y \\ N_z \end{pmatrix}. \quad (1)$$

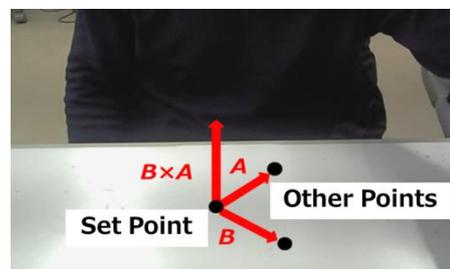


Figure 12: Calculation of normal vectors on arbitrary coordinates

Next, this system calculates a transformation matrix to convert the coordinates system whose origin is a set point to Sens3D coordinates system. By using the z-axis

direction vector of Senz3D $\mathbf{S} = (0,0,1)$ and the normal vector \mathbf{N} , this system calculates a rotation angle θ and a rotation axis $\mathbf{n} = (n_x, n_y, n_z)$ from inner product and outer product

$$\theta = \cos^{-1} \left(\frac{\mathbf{S} \cdot \mathbf{N}}{|\mathbf{S}| |\mathbf{N}|} \right), \quad (2)$$

$$\mathbf{n} = \mathbf{S} \times \mathbf{N} = \begin{pmatrix} n_x \\ n_y \\ n_z \end{pmatrix}. \quad (3)$$

By using θ and \mathbf{n} , this system calculates quaternion \mathbf{q} and the transformation matrix \mathbf{R}

$$\mathbf{q} = \begin{pmatrix} q_x \\ q_y \\ q_z \\ t \end{pmatrix} = \begin{pmatrix} \sin \left(\frac{\theta}{2} \right) q_x \\ \sin \left(\frac{\theta}{2} \right) q_y \\ \sin \left(\frac{\theta}{2} \right) q_z \\ \cos \left(\frac{\theta}{2} \right) \end{pmatrix}, \quad (4)$$

$$\mathbf{R} = \begin{pmatrix} 1 - 2q_y^2 - 2q_z^2 & 2q_x q_y + 2t q_z & 2q_x q_z - 2t q_y & p_x \\ 2q_x q_y + 2t q_z & 1 - 2q_x^2 - 2q_z^2 & 2q_y q_z + 2t q_x & p_y \\ 2q_x q_z - 2t q_y & 2q_y q_z + 2t q_x & 1 - 2q_x^2 - 2q_y^2 & p_z \\ 0 & 0 & 0 & 1 \end{pmatrix}, \quad (5)$$

where p_x , p_y and p_z are the coordinates of a set point from Senz3D. This system draws a CG object (Rectangular) on the coordinate system whose origin is a set point as shown in Figure13 by using this transformation matrix \mathbf{R} and OpenGL.

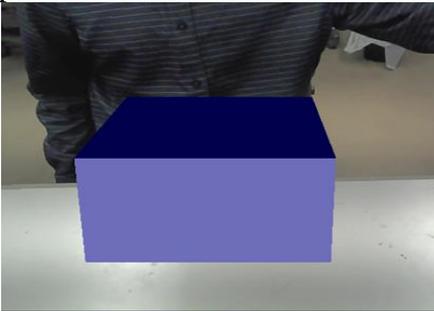


Figure 13: CG object drawing

(3) Detecting finger position and posture

In the detecting a finger position, this system extracts the specific color area and obtains the depth information of the extraction region from Senz3D shown in Figure14. By using this depth information and the screen coordinates, this system calculates three-dimensional

coordinates (S_x, S_y, S_z) of extracted region. By using this coordinates (S_x, S_y, S_z) and \mathbf{R} , this system calculates a finger position (F_x, F_y, F_z) from a set point.

$$\begin{pmatrix} F_x \\ F_y \\ F_z \\ 1 \end{pmatrix} = \mathbf{R}^{-1} \begin{pmatrix} S_x \\ S_y \\ S_z \\ 1 \end{pmatrix}. \quad (6)$$



Figure 14: Acquire finger position coordinates

(4) Judgement of contact

When the acquired fingertip coordinates (F_x, F_y, F_z) overlaps the drawn rectangular parallelepiped region, We judge it contact of the fingertip and rectangular parallelepiped.

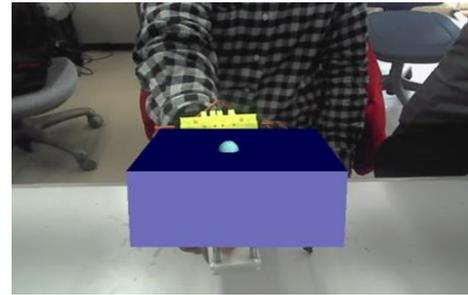


Figure 15: Contact judgment

(5) Calculation of the motor rotation angle

In calculating the control amount of the motor, the rotation angle of the motor for transmitting to the Arduino Uno is calculated. Let x be the push amount when the fingertip is pushed into the CG object.

Also, since the CG object used in this research is non-rigid, the control amount F of the plane interface is calculated from the following equation by physical model of the spring. Also, let the spring constant be k .

$$F = kx \quad (0 \leq k < 1). \quad (7)$$

As shown in Figure16, since F corresponds to a part of the circular arc of the servo horn, the rotation angle A of the motor is calculated using F and the radius R of the servo horn. And

transmits the calculated rotation angle to the Arduino Uno by serial communication.

$$A = \frac{180^\circ}{\pi R} F. \quad (8)$$

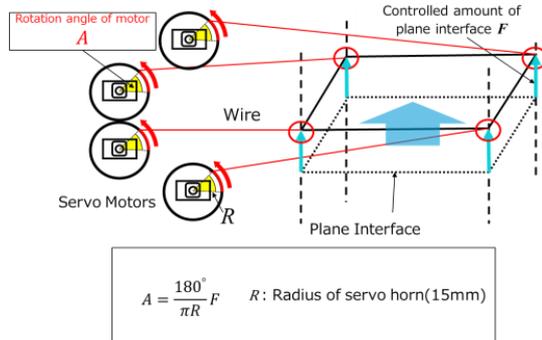


Figure 16: Motor rotation angle calculation

(6) Controlling the motors

The servo motors receive the rotation angle of the motor calculated in equation(8) with Arduino Uno and rotate the motor. Each movable point of the plane interface is pulled up by a servomotor using a wire. As the finger touches the plane interface, the user receives a force sense presentation.

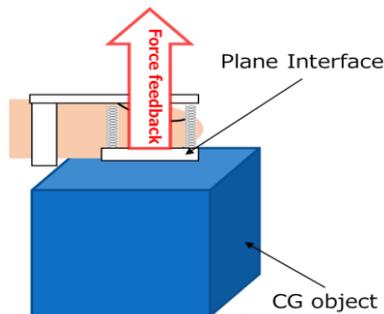


Figure 17: Motor control and contact with a CG object

4 Evaluation Experiments

4.1 Overview of the experiments

We had an evaluation experiment for the proposed haptic device. In this experiment, in fact, ten subjects actually got the operation designation of the haptic desk of this study, and conducted a comparative experiment on the evaluation of each interface.

Evaluation items are the following three items, and the evaluation for each was judged by a 5-step evaluation with 1 at the lowest and 5 at the highest.

① Do you feel non-rigid object though the haptic device?

- ② Is the reaction rate after touching the object good?
- ③ Do you feel detect finger position naturally?

4.2 Discussion

Table 1 shows the experimental results of items ① to ③. The evaluation that the haptic presentation of non-rigid body can be expressed from the experiment result of item ① is generally good. However, we thought that if we expressed the visual expression part like a non-rigidly similar rubber film, it got even better results. Although it was very high from the experimental result of item ②, some users sometimes feel that there is a delay from touching CG object to force sense presentation. Since this is a problem caused by the rotation speed of the motor, we thought that it could be improved by replacing the motor with one with a higher rotation speed.

It could be said that the evaluation on the experiment result of item ③ is generally high. We thought that this was a good evaluation as a result of recognizing fingertips using color information.

Table 1: Results of the evaluation

No.	①	②	③
Average score	4.20	4.40	4.20
A standard deviation	0.70	0.50	0.70

CONCLUSION

In this paper, we proposed a non-rigid force sense presentation method for a finger-mounted type haptic device. In the evaluation experiment, three items were prepared and it was verified whether the created haptic device can express a non-rigid object. As a result, the average value is generally high and it is considered to be a good device. We aim to improve the device, make it possible to grasp CG objects, and construct an interface using HMD (Head Mounted Display).

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