Development of A Finger Mounted Type Haptic Device Using A Plane Approximated to Tangent Plane

Makoto Yoda
Department of Information System Science
Graduate School of Engineering
Soka University, Soka Univ.
Tokyo, Japan
e-mail:e16m5223@soka-u.jp

Hiroki Imamura
Department of Information System Science
Graduate School of Engineering
Soka University, Soka Univ.
Tokyo, Japan
e-mail:imamura@soka.ac.jp

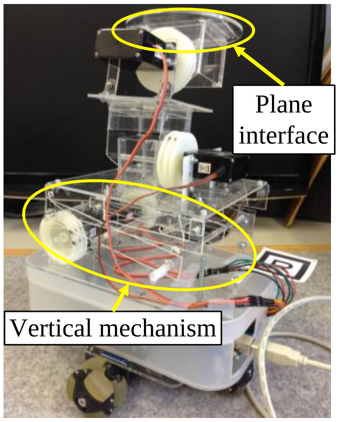
***Abstract*—In recent years, several researches of haptic devices have been conducted. By using conventional haptic devices, users can perceive touching an object, such as Computer Graphics (CG) by a force feedback. Since conventional haptic devices provide a force feedback from a single point on an object surface where users touch it, users touch an object by point contact. However, conventional haptic devices cannot provide users with a sense such as humans touching an object with a finger pad because a finger pad does not touch an object by point contact but surface contact in reality. In this paper, we propose a novel haptic device. By using this haptic device, users can perceive the slope of a CG object surface when they put fingers on it without tracing. Moreover, users can perceive grabbing a CG object with finger pads. To grab CG object, we mount the plane interface of the haptic device on each two fingers. Then, users can perceive the slope of a CG object surface where users are touching. Each plane interface provides users with the slope approximated to a tangent plane of area where they touched. In the evaluation experiments, the subjects in this experiment evaluated this haptic device. From the results, the subjects could perceive the slope of a CG object surface. In addition, they could perceive grabbing a CG object.**

Keywords-haptic device; plane interface; force feedback .

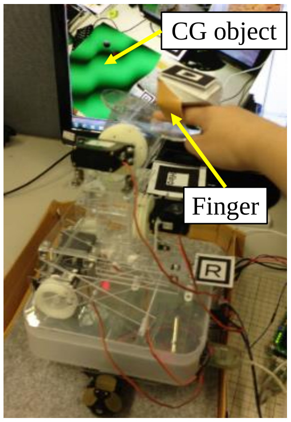
I. INTRODUCTION

In recent years, researches of human interface using Augmented Reality (AR) have been conducted. In order to touch CG objects that are drawn by AR, haptic devices have been developed. By using a haptic device, users can perceive touching CG objects by processing a force feedback. Therefore, haptic devices are expected to be used in applications such as remote control of robots and computer games.

Examples of conventional haptic devices include Falcon [1], PHANToM [2] and Dexmo [3]. Falcon and PHANToM are classified into a grounded type. This type can provide users with accurate force feedback because its fulcrum is fixed on the table. Dexmo is classified into a finger mounted type. This type can provide users with perception of grabbing CG objects easily. In addition, users can operate the device without operating range limitation. These haptic devices have been developed as a point contact haptic device. By using this type of haptic device, users can perceive touching CG objects because they are provided with a force feedback from a single point on the CG object surface where they touched. In case of perception of an objects shape, from visual information, users perceive CG objects shape of visible part. As invisible part, users must perceive CG objects shape by touching the surface. However, in a point contact type, to perceive CG objects shape, users must trace the surface because they perceive only touching CG objects. Therefore, they cannot work smoothly in that part. In order to perceive CG objects shape without tracing the surface, the direction of a force feedback must change according to a surface shape where users touched. Our laboratory focused on this characteristic. In addition, our laboratory has developed a haptic device based on an approximated plane (HaAP) [4] that is shown in Figure 1. HaAP is a grounded type. Moreover, HaAP is a surface contact type haptic device which has a plane interface that is shown in Figure 1-(a). Since as shown in Figure 1-(b), the plane interface provides users with a force feedback by being approximated to the tangent plane on a CG object surface where they touched, users can perceive the shape from the surface slope without tracing the surface. In this device, users are limited to operate HaAP in range of the HaAP vertical mechanism within 10 cm.



(a). Appearance of HaAP



(b). Operating state

Figure 1. HaAP.

In this paper, we propose a novel haptic device. This haptic device realizes three things. First, users are provided with a force feedback by the plane interface providing the

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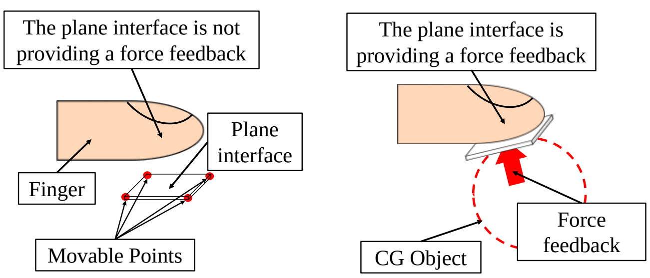
slope approximated to the tangent plane on a CG object surface. Second, users can operate this haptic device without operating range limitation. Third, by using this haptic device, users can perceive grabbing a CG object. To realize that, we develop a haptic device having characteristics of a finger mounted type and a surface contact type.

This paper is structured as follows: First, the outline of the proposed haptic device is explained in section II. In section III, the hardware construction, the system overview and the system flowchart are proposed. Evaluation experiments are carried out for the proposed haptic device in section IV. Finally, conclusions and future works end this paper.

II. OUR APPROACH

Figure 2 shows the outline of the proposed haptic device. This device uses a plane interface having four movable points. These four movable points operate up and down separately.



(a). Initial state (b). Operating state

Figure 2. Outline of the proposedhaptic device.

Figure 2-(a) shows the initial state. In this state, the user is not touching a CG object. Figure 2-(b) shows the operating state. In this state, the user is touching a CG object. The plane interface provides a finger pad with a force feedback by approximating the tangent plane on the CG object.

III. THE PROPOSED SYSTEM

A. Hardware condtruction

Figure 3 shows the appearance of the proposed haptic device.

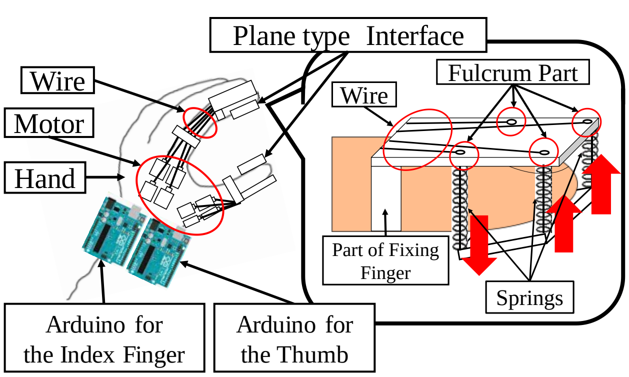


Figure 3. Appearance of the proposed haptic device.

This device is a glove type and composed of Arduino Uno, four servo motors (GWS Servo PIC+F/BB/F), four springs and a plane interface for each finger. Eight motors are mounted in the back of the hand. In addition, each motor is connected to Arduino Uno for the index finger and Arduino Uno for the thumb, respectively. Arduino Uno controls four motors in each finger. These motors pull up the movable points of the plane interface with wires. When motors pull up, wires hang at the fulcrum part. Each spring adheres to each movable point.

B. System overview

Figure 4 shows the system overview. This system consists of PC, Display, Web-Camera and the proposed haptic device. The user attaches markers on fingers and wears the proposed haptic device.

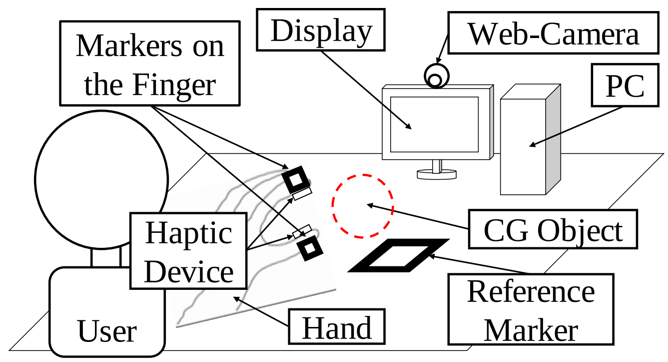


Figure 4. System overview.

C. The system flowchart

Figure 5 shows the system flowchart. The following is the explanation about processing flow in this system. In the following section, we explain each process in the flowchart.

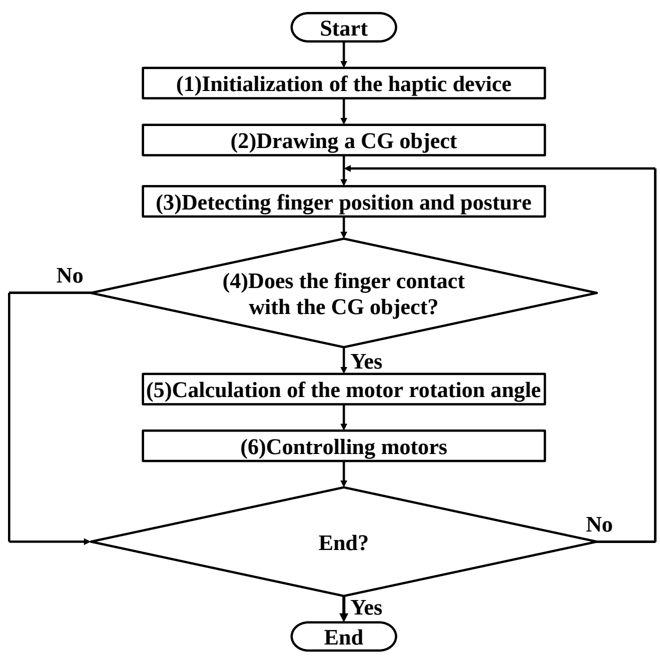


Figure 5. Flowchart.

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1) Initialization of the haptic device: Arduino Uno controls motors to make springs natural length.

2) Drawing a CG object: Based on the reference marker, ARToolkit [5] draws Sphere CG object or Sin-cos curve CG object that is shown in Figures 6 and 7, respectively.

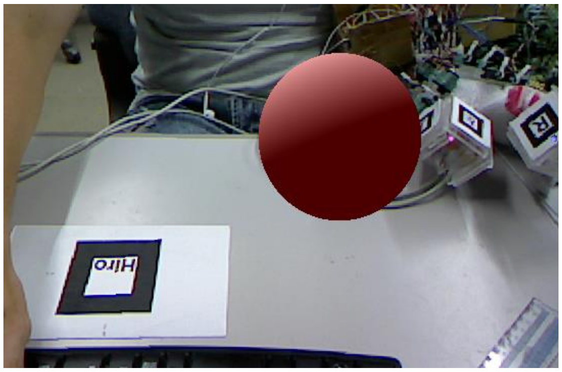

Figure 6. Sphere CG object

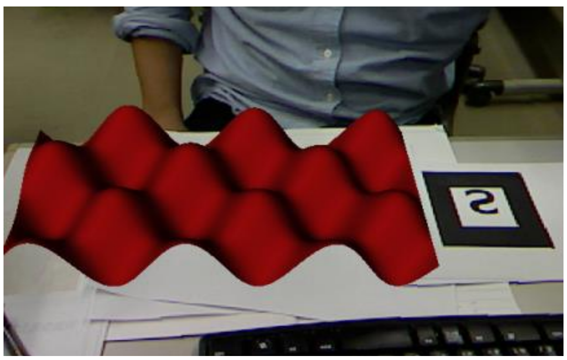

Figure 7. Sin-cos CG object

3) Detecting finger position and posture: Figure 8 shows detecting the marker on each finger position and posture. The system recognizes the reference marker and the marker on each finger from the image that is captured by the web camera. By using ARToolKit, the system obtains position (X,Y,Z) of the marker on each finger from the reference marker. In addition, by using ARToolKit, the system also calculates F_r that denotes the roll angle and F_p that denotes the pitch angle of the marker on each finger.

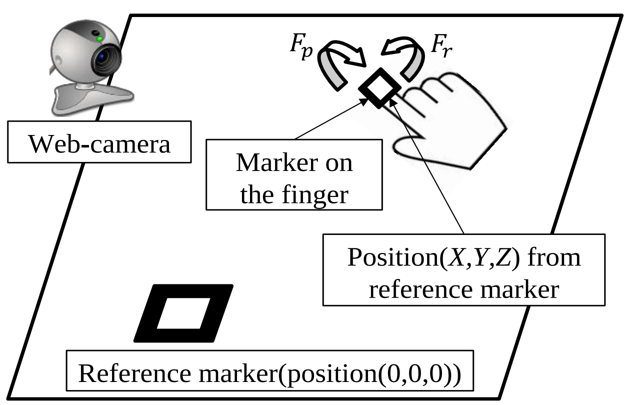

Figure 8. Detecting the finger position and posture.

4) Judgement of contact: In the case of a Sphere CG object, as shown in Figure 9, when the length between the marker on the finger position and the center of Sphere CG object is within radius of Sphere CG object, the system judges contact.

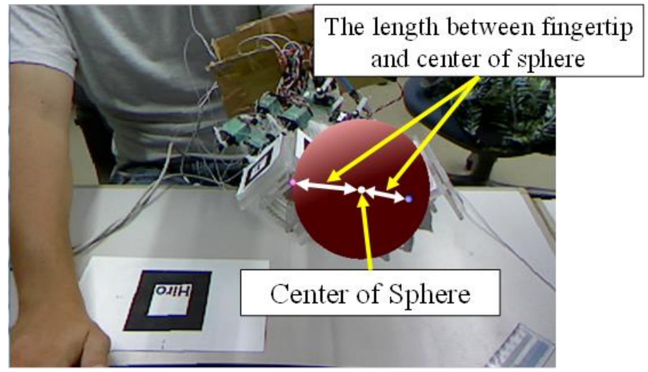

Figure 9. Touching Sphere CG object

In case of Sin-cos curve CG object, the system calculates Z-coordinate on Sin-cos curve CG object. The following is the equation of Sin-cos curve.

$$A \sin X \cos Y = Z, \tag{1}$$

where A is amplitude and X, Y and Z are X, Y and Z-coordinate on Sin-cos curve CG object. By substituting X and Y-coordinate of the marker on the finger for this equation, the system obtains Z. As shown in Figure 10, when Z-coordinate of the marker on the finger is under Z, the system judges contact.

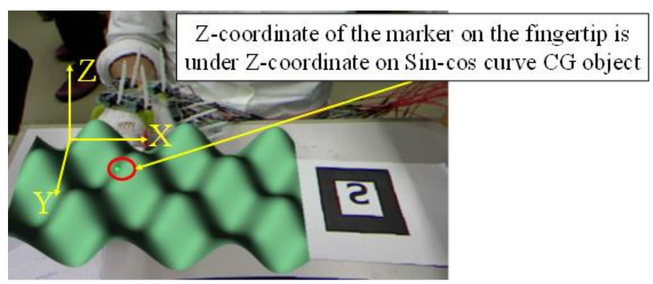

Figure 10. Touching Sin-cos curve CG object.

5) Calculation of the motor rotation angle: The system calculates the normal vector on touching point.

In case of a Sphere CG object, the vector from the center of Sphere CG object to the touching point is defined as the normal vector on the touching point.

In case of Sin-cos curve CG object, Sin-cos curve CG object is composed of many planes. Figure 11 shows calculation of the normal vector on the touching point. The system uses the equation of vector product

$$\boldsymbol{N} = \boldsymbol{A} \times \boldsymbol{B}, \tag{2}$$

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where ***A*** and ***B*** are the vectors from the touching point to other points on the plane that includes the contact point. The system obtains the normal vector from right hand screw rule.

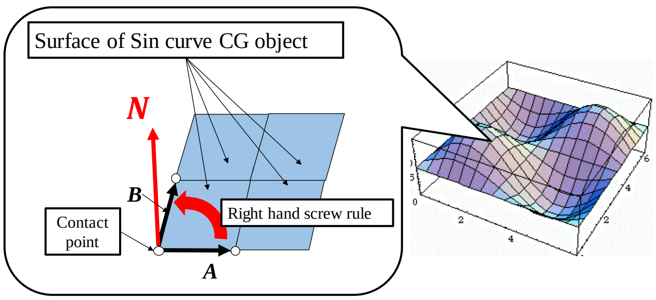


Figure 11. Calculation of the normal vector.

From the normal vector, the system calculates the roll angle and the pitch angle of the tangent plane on touching point. Figure 12 shows the calculation of the tangent plane slope on touching point in X-Z plane and Y-Z plane. The system uses

$$T_p = 90° - \theta_y, \quad (3)$$

$$T_r = 90° - \theta_x \quad (4)$$

to obtain the roll and pitch angle of the tangent plane. θ_x denotes the angle between x-axis and the normal vector and θ_y denotes the angle between y-axis and the normal vector. Using (3) and (4), the system obtains T_r that denotes the roll angle of tangent plane and T_p that denotes the pitch angle of the tangent plane.

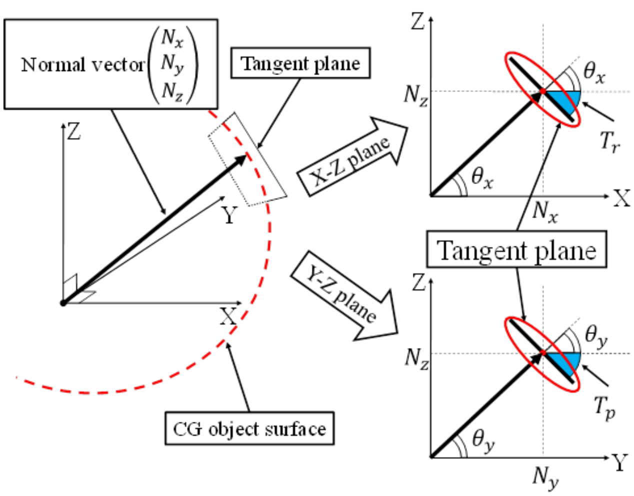


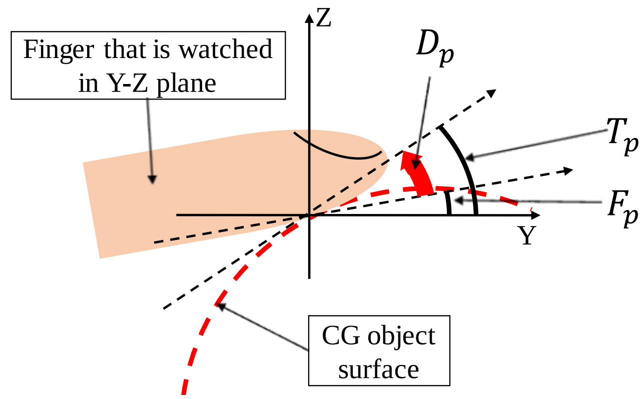
Figure 12. Calculation of the tangent plane angle.

Using equations (5) and (6), the system calculates the difference between the angle of the marker on the finger and that of the tangent plane.

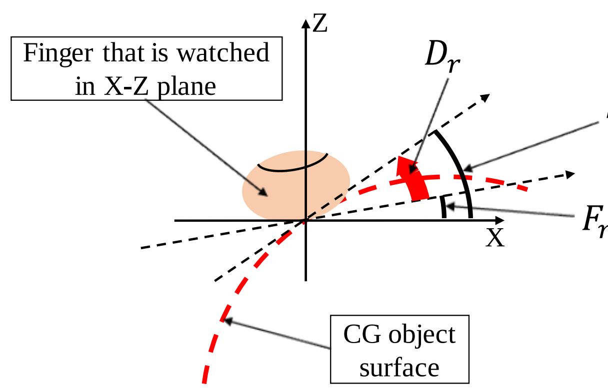
$$D_p = |T_p - F_p|, \quad (5)$$

$$D_r = |T_r - F_r|. \quad (6)$$

This difference is the plane interface slope that is shown in Figure 13. F_p and F_r are shown in Figure 8. Figure 13-(a) shows D_p that denotes the difference between F_p and T_p. Figure 13-(b) shows D_r that denotes the difference between F_r and T_r.



(a). Difference of the pitch angle.



(b). Difference of the roll angle.

Figure 13. Calculation of the plane interface slope.

The system calculates the operation length of movable point from the plane interface slope. Figure 14 shows two lengths (L1 and L2). These two lengths are defined

$$\mathrm{L1} = \frac{A}{2}\sin(|D_p|) + \frac{A}{2}\sin(|D_r|), \quad (7)$$

$$\mathrm{L1} = \left|\frac{A}{2}\sin(|D_p|) - \frac{A}{2}\sin(|D_r|)\right| \quad (8)$$

as the operation length of movable points. Where A is the length of one side on a plane interface. Using (7) and (8), the system calculates these lengths.

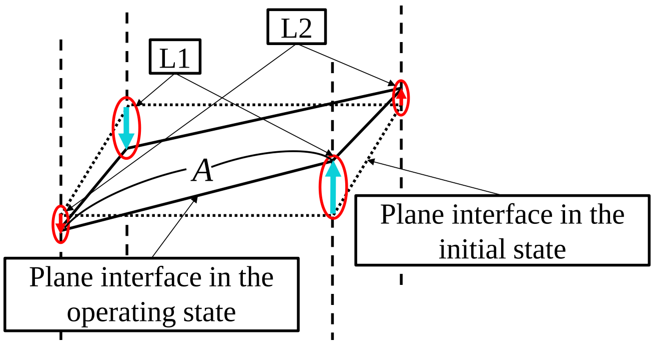


Figure 14. The operation length of movable points.

Figure 15 shows the angle of motor rotation. The system uses

$$A1 = 2\sin^{-1}\left(\frac{L1}{2\times R}\right), \quad (9)$$

$$A2 = 2\sin^{-1}\left(\frac{L2}{2\times R}\right) \quad (10)$$

to calculate the angle of motor rotation, where R denotes the length of servo horn. A1 and A2 are the amount of controlling motors. The system sends this amount to each Arduino Uno by serial communication.

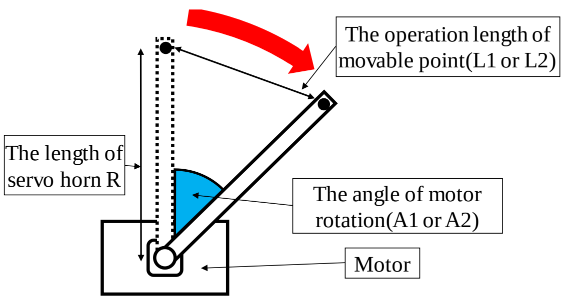
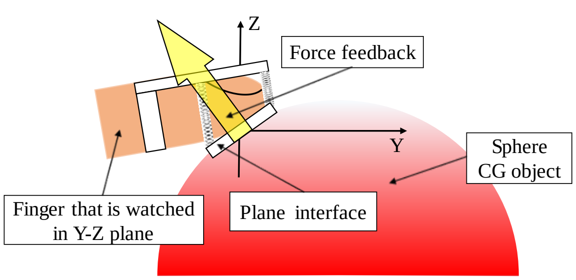
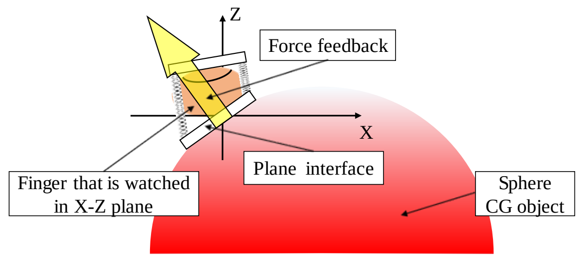


Figure 15. The angle of motor rotation.

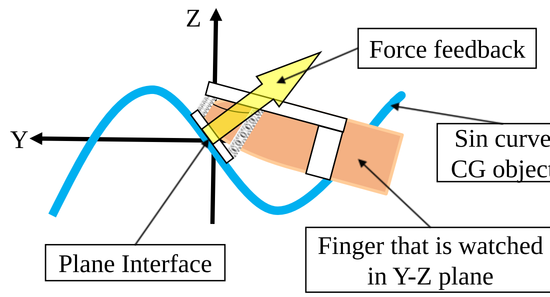
6) Controlling the motors: Arduino Uno receives the amount of controlling motors and controls motors. Motors pull up each movable point with wires. Figure 16-(a) and (b) shows providing a finger with a force feedback when users touched Sphere CG object in Y-Z plane and X-Z plane respectively. Figure 16-(c) and (d) shows providing a finger with a force feedback when users touched Sin-cos curve CG object in Y-Z plane and X-Z plane respectively.



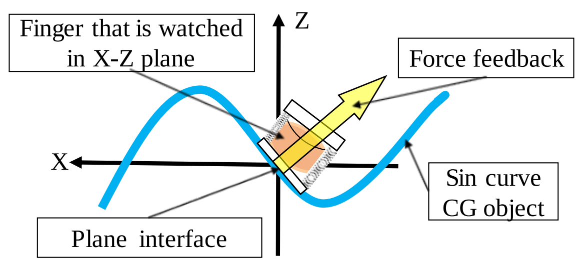
(a). Y-Z plane.



(b). X-Z plane.



(c).Y-Z plane.



(d). X-Z plane.

Figure 16. The plane interface that provides a force feedback.

IV. EVALUATION EXPERIMENTS

A. Overview of the experiments

We had an evaluation experiment for the proposed haptic device. Sin-cos curve CG object is used in order to evaluate whether users can perceive the slope of the CG object surface or not. In addition, a Sphere CG object is used in order to evaluate whether users can perceive grabbing a CG object or not. Eleven subjects used the proposed haptic device. After that, they evaluated following items with a 5-grade score:

In case of Sin-cos CG object,

- When you touched the CG object with one finger, you perceived the slope of the CG object surface at once (Item1).
- When you touched and traced the surface of the CG object with one finger, you perceived the asperity of the CG object surface (Item2).

In case of Sphere CG object,

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- When you touched the CG object with one finger, you perceived the slope of sphericity (Item1).
- When you touched and traced the surface of the CG object with one finger, you perceived the shape of sphericity (Item2).
- When you touched the CG object with two fingers, you perceived touching the CG object (Item3).
- When you touched the CG object with two fingers, you perceived grabbing the CG object (Item4).

Evaluation values are from 1 to 5 (1 : ”Strongly disagree”, 2 : ”Disagree”, 3 : ”Neutral”, 4 : ”Agree”, 5 : ”Strongly agree”).

B. Discussion

Table 1 shows the results of Sin-cos curve CG object. Table 2 shows the results of Sphere CG object. Each result shows the average score and the standard deviation.

TABLE I. RESULTS OF SIN-COS CURVE CG OBJECT

Item	**Sin-cos curve CG object**	
	Average score	***A standard deviation***
1	4.64	0.64
2	4.55	0.50

TABLE II. RESULTS OF SPHERE CG OBJECT

Item	**Sphere CG object**	
	Average score	***A standard deviation***
1	4.09	0.90
2	4.00	0.85
3	4.18	0.94
4	4.27	0.96

From these results, in Item1 of Tables 1 and 2, we see that users perceived the slope of CG object without tracing the surface. In Item2 of Tables 1 and 2, the results show that users perceived the asperity by tracing the surface. In addition, in Item3 and Item4 of Table 2, we see that users perceived grabbing a CG object. Therefore, we consider that the proposed haptic device can provide users with perception of the CG object surface slope. Moreover, we consider that users can perceive grabbing a CG object by using the proposed haptic device. In addition, from Tables 1 and 2, we see that the average score in Table 1 is higher than that in Table 2. Since the surface of Sin-cos curve CG object is more complex than that of Sphere CG object, the accuracy of the proposed haptic device is improved when CG object have complex surface.

V. CONCLUSIONS AND FUTURE WORKS

In this paper, we proposed a novel haptic device. The proposed haptic device has a plane interface to provide a slope approximated to the tangent plane of the CG object area where users touched. In addition, to perceive grabbing a CG object, the proposed haptic device is designed as a finger mounted type. After evaluation experiments, we see that the proposed haptic device can provide users with perception of the CG object surface slope without tracing the surface and perception of grabbing the CG object. However, we consider that users cannot grasp the sense of the distance between finger and a CG object easily. To solve the issue, we improve the proposed haptic device to grasp the sense of the distance more easily by using Head Mounted Display (HMD). In the future, we will improve the operability of the proposed haptic device by lightening the device. In addition, by using Leap Motion, we will improve the accuracy of detecting finger position and posture.

REFERENCES

[1] Novint Technologies, Inc, “http://www.novint.com/index.php/ novintfalcon” (last accessed March, 2016)

[2] Geomagin, Inc, “http://www.geomagic.com/en/products/phantom-desktop/overview” (last accessed March, 2016)

[3] Dexta Robotics, Inc, “http://www.dextarobotics.com/products /dexmo”(last accessed March, 2016)

[4] A. Kawazoe, K. Ikeshiro, and H. Imamura, “A Haptic Device based on An Approximate Plane HaAP. ACM Siggraph Asia 2013 Posters”, 2013, Hong Kong. CD-ROM.

[5] H. Kato, “ARToolKit:Library for Vision-based Augmented Reality” , Technical report of IEICE, PRMU, 101(625), 2002, pp.79-86.

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