Effective Output Patterns for Torque Display "GyroCube"

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Abstract

In the previous paper in ICAT2002, we reported that a non-grounded palm-top torque display "GyroCube" was developed. Although it requires no grounding base for supporting the counter torque to the objective one, and consequently is suitable for mobile use, it generates superfluous negative resetting torque after presenting the objective one in terms of principle. When the control voltage is increased uniformly over the operation time to increase the magnitude of torque, the resetting torque becomes stronger as same as the objective torque becomes stronger. It is not clear whether the stronger resetting torque would weaken the effect of the objective torque, or it could strengthen the sensitivity of human palm because of the after-effect of the human sensing system. Therefore we conducted new experiments concerning the above issue. The results are as follows. There was no predominant difference between stronger resetting torque case and weaker one. The minimum torque stimulus the user could sense was approximately 200 [gfcm] in either hands. There was no significant difference in the ways of grasping the device "GyroCube". One of the applications of such device would be, for example, a haptic navigation system for pedestrians.

Key words: haptic sensation, virtual reality, torque feedback device

1. Introduction

From the early days of emerging virtual reality technology, many force feedback devices have been developed in the research field of virtual reality. Force feedback devices are classified mainly into two types; the earth grounding, and the body grounding. The earth grounding device, in principle, requires the grounding base for supporting the counter force or torque. For example, PHANToM[1], SPIDAR[2] and HapticMaster[3] are such devices. These devices aren't suitable for portable one and the operation area is limited to the ranges where the devices can reach. On the other hand, body grounding device requires no earth grounding base and is suitable for portable one. For example, Rutger Portable Master[4], HapticGEAR[5] and HapticJoystick[6] are such devices. These devices utilize the user's body as the grounding base. This method, however, is difficult to present the haptic feeling from external objects. To overcome this problem, we developed a non-grounded palm-top torque display "GyroCube"[7] that generates torque by itself, using time differential of angular momentum. As another non-grounded display, the force display using gyro moment was developed[8].

In the previous paper[9], we conducted the experiment to obtain sensing characteristics of human palm using "GyroCube". But in the experiments, there were some problems remained.

1. This device needs much time to reduce the rotor's spin velocity to the initial state periodically.
2. This device cannot generate torque to inform a constant direction for a long time.
3. It isn't clarified whether these sensing characteristics are influenced by the ways of grasping this device or not.

To overcome these problems, we conducted new experiments using this device as follows.

2.System Configuration

A torque display "GyroCube" is shown in **Figure 1.** In order to change the angular momentum in arbitrary orientation in a space without rotating the posture of spinning rotor, three rotors were arranged in the device's cube frame so that the respective rotors intersect in an orthogonal state. A wheel made of brass was installed in the respective rotors' rotation axes in order to obtain stronger angular momentum.

To control the torque of the rotors inside "GyroCube", AC servo motor system was adopted to control the rotation velocity. Therefore at the PC side, a D/A converter board is installed to control the serve motors (see **Fig. 2**).

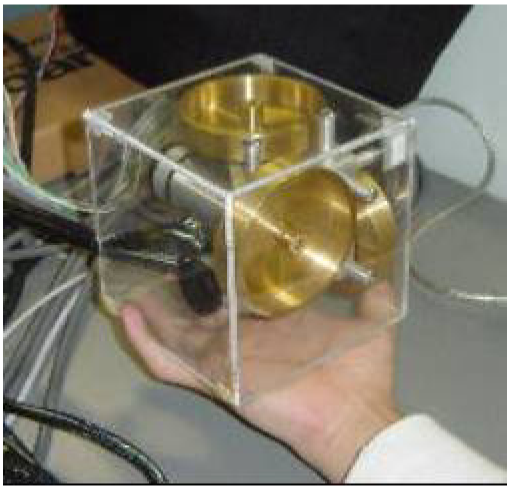


Fig. 1 GyroCube

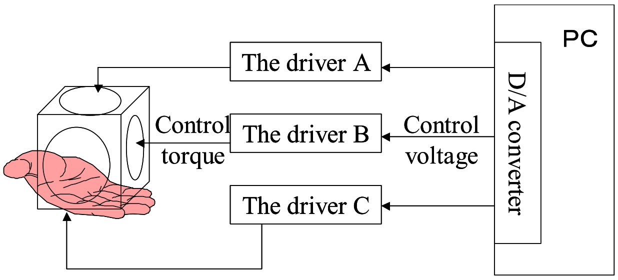


Fig.2 System of GyroCube

The torque τ, that is the time differential of angular momentum vector L, is derived as the followings:

The angular momenta L_i rotating at the angular velocity ω_i around x, y, z axes are (where I_i is the moment of inertia around each axes)

$$L_i = I_i \omega_i, \text{ where } i=x,y,z$$

The compound angular momentum vector L is

$$L = L_x i + L_y j + L_z k$$

Where, *i, j, k* mean the unit vector of x, y, z axes respectively. The torque τ is found as follows:

$$\tau = dL / dt$$

The moment of inertia of the wheel is $2.3*10^{-4}$[kg*m^2]. For example, when a torque of 600[gfcm] driven by 3.3 [V] accelerates the wheel to approximately 2,440 [rpm] within one second from the initial resting state,.

To present an objective torque by accelerating angular momentum repeatedly, it is necessary for the rotor to reduce to the initial velocity periodically. When the rotor is accelerated from initial velocity, "GyroCube" generates the objective torque, and as next, when the rotor is decelerated to initial velocity, it generates superfluous resetting torque (**see Fig. 3**). The generated torque is proportional to the control voltage by using torque controlling mode. In terms of the principle, "GyroCube" can present only a torque, but neither linear force nor buoyancy.

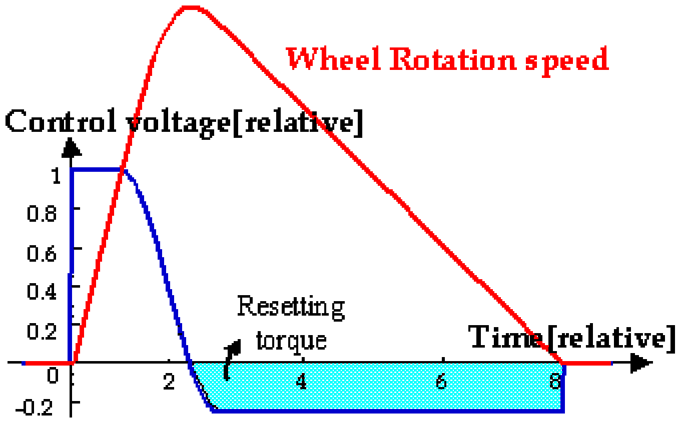


Fig.3 Control voltage waveform and wheel rotation speed

3. Experiment 1

3.1 Purpose of experiment 1

In the previous experiment, it was found that the dependence of the torque and the torque sensitivity to the directions of both palms are approximately symmetrical with respect to the sagittal plane. In the experiment, the magnitude of resetting torque was so weak that it was not perceived consciously. When the control voltage is increased uniformly over the operation time to increase the magnitude of torque, the resetting torque becomes stronger as same as the objective torque becomes stronger. It is not clear whether the stronger resetting torque(**see Fig. 4**) would weaken the effect of the objective torque, or it could strengthen or increase the sensitivity of human palm because of the after-effect of the human sensing system.

In order to clarify these questions, we carried out the experiment 1. Before this experiment, we carried out pre-experiment to select the two resetting torque conditions.

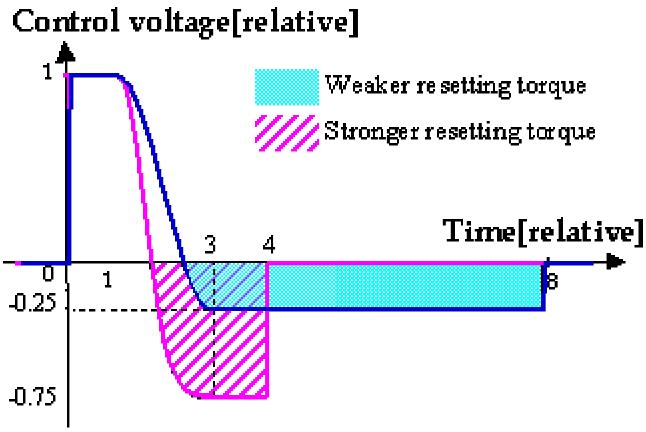


Fig. 4 Control voltage waveform

3.2 Experimental Design

[Conditions]

-Control voltage: (6.0, 4.0, 2.0)[V] Equivalent torque is 1080[gfcm], 720[gfcm], 360[gfcm] respectively.
-Resetting torque: (0.25, 0.75)[Relative]
-Presenting time:1.6[s](weak resetting torque) 0.8[s](strong resetting torque)
-Trial times: three times
-The way of grasping: The same as **Figure 1**.
-Presenting directions: eight directions (North, South, East, West, Northeast, Southeast, Southwest, and Northwest).

Hereafter we abbreviate the Southwest as SW, the South as S and so on. For example, when a torque is presented to middle fingertip direction, we call it "N (the North)". When a torque is presented to wrist direction, we call it "S (the South)".

Eight directed stimuli were presented nine times randomly with intervals. Three of the trials were strong signals, and other three were middle, the other three were weak. Total 144 torque stimuli were presented.

[Methods]

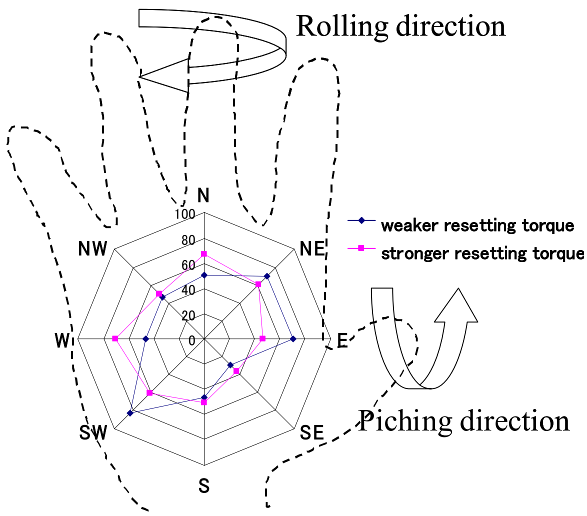
A Subject put his or her right arm on the table while seated on a chair, and held the device with his or her right palm. The device was covered with a cloth in order to prevent the subject's haptic sensation from being interfered with the visual information of the rotations.

[Subjects]

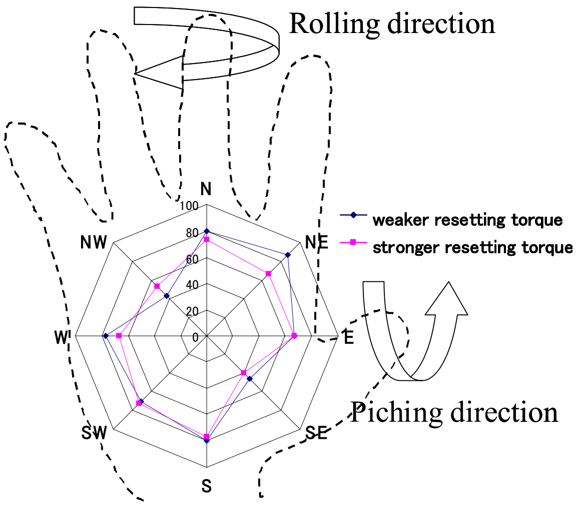
Total 10 male and female subjects aged 20 to 30 participated in this experiment.

3.3 Results and Discussions

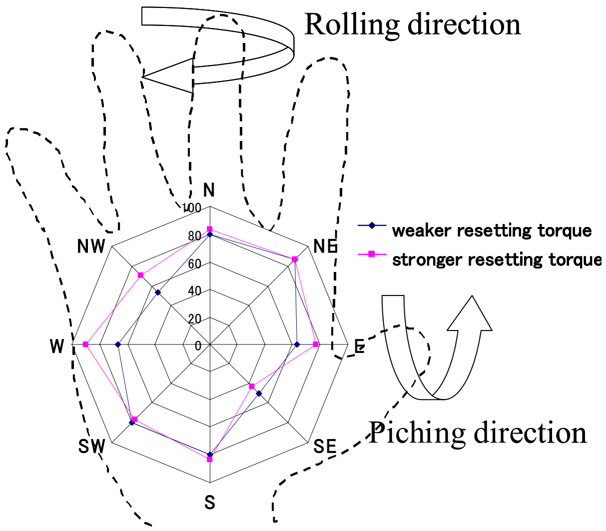
The radar charts (**Figure 5**) show the correct answer ratios for eight directions for each control voltages, 2.0V, 4.0V, 6.0V, and the averaged respectively. As the control voltage is increased uniformly over the operation time from 2.0V to 6.0V, the correct answer ratios and the deviation are improved.



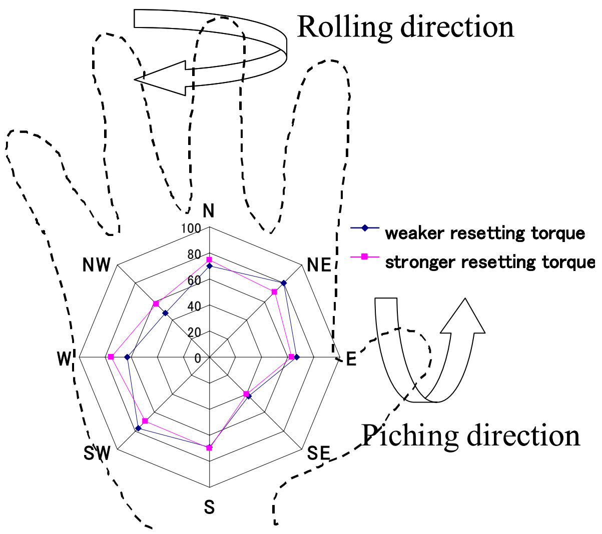
(a) The control voltage is 2.0[V]



(b) The control voltage is 4.0[V]



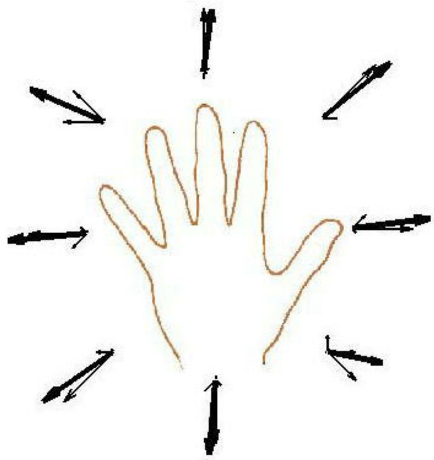
(c) The control voltage is 6.0[V]



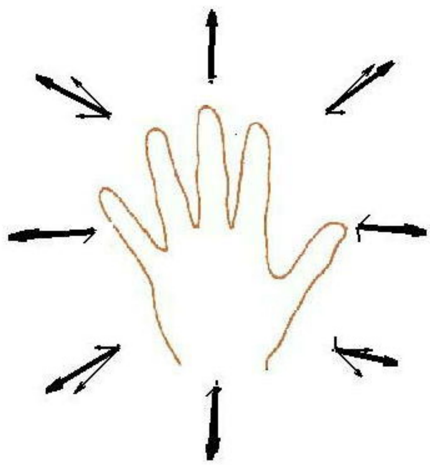
(d) The average of three voltage cases

Fig. 5 Correct answer ratios for eight directions

In the Figure 6, the thin vectors represent the perceived directions and the number of subjects who felt that direction. The thick vector shows the compound of thin vectors. This vector means expectation, that is, the more answers deviate, the shorter the length of compound vector becomes. Figure 5 and Figure 6 show that there was no significant difference between weaker resetting torque and stronger resetting torque.



(a) Weaker resetting torque



(b) Stronger resetting torque

Fig. 6 Variation of perceived direction 1

4. Experiment 2

4.1 Purpose of experiment 2

In the previous paper, as it is difficult to make the rotor keep accelerating to generate torque in a constant direction for a long time, there was necessity to decelerate the rotor to the initial state periodically. However this device is able to generate haptic sense which shows a direction for a long time by switching the accelerating wheel one after another. For example using X rotor and Y rotor, first the X rotor starts accelerating, then Y rotor accelerates while the X rotor is decelerated to the initial state. That is a spinning top's precession. Continuing this action would realize generating rounding torque which can inform a direction for a long time.

However, in this case, there are the two directions of the torque direction rotation, clockwise or anti-clockwise, like spinning top's rotation on the palm forming a circle. This precession information was utilized in this experiment 2. This information is effective because it would enable the subjects to understand the direction of the precession's rotation (clockwise or anti-clockwise) for some time, while being presented the continuous torque.

Using the above way, the purpose of the experiment2 is to clarify how much strength of torque is required in order to make the subjects understand the directed torque accurately. In short terms, to find out the threshold of sensitivity (the minimum torque that the user can sense).

4.2 Experimental Design

[Conditions]
-Control voltage:(start from 0.2[V])
In order to clarify the minimum strength of torque force that the user can sense, this device presented the torque step by step in 0.2[V](36[gfcm]) interval starting from 0.2[V], until the subject feels the clockwise or anti-clockwise stimulus accurately.
-Resetting torque:(0.25) [Relative]
-Presenting time: 3.2[s]
-Presenting directions:(clockwise, anti-clockwise)
The center of the spinning top' is the normal of the palm.
-The way of grasping: The same as **Figure 1**.
We repeated these six trials for each of left and right palm. Three of the presented torques were clockwise torque and the other were anti-clockwise. These six stimuli were randomized as a stimulation sequence. Methods, the number and the age of subjects are the same as the experiments 1.

4.3 Results and Discussions
Table 1 shows the averaged threshold strength of the torque for the clockwise and anti-clockwise spinning top's rotations for each palm. These thresholds of sensitivity were approximately 200 [gfcm] in either hand. There are statistically no significant difference between the left and right palm or clockwise torque and anti-clockwise one in the sensitivities with respect to the strength of presenting torque.

Table 1. Averaged threshold of torque [gfcm]

[gf.cm]	Clockwise	Anti-clockwise
Average of the left palm	198.0	189.0
Average of the right palm	208.8	199.8

5. Experiment 3

5.1 Purpose of experiment 3
According to the previous paper[8], "GyroCube" were designed that the center of the device's cube frame is equal to the center of gravity of the device, and they conducted the experiments and clarified whether the device can generate the same torque or not, by the same voltage for the each directions using the torque sensor which can measure the pressure. However we need to clarify whether the device was really manufactured symmetrically or not, and whether the cable connecting the device's cube and the device influenced the result of those experiments or not, by conducting the following experiment to the subjects.

5.2 Experimental Design

[Conditions]
-Control voltage: (4.0, 2.8)[V]
equivalent torque is 720[gfcm,] 504[gfcm] respectively.
-Resetting torque: (0.25)[Relative]
-Presenting time:1.6[s]
-The way of grasping:
Pattern 1: The same as **Figure 1**(Experiment 1).
Pattern 2:Rotated 90 degrees around the normal of the palm (**see Fig. 7**)
[Subjects]
Total 3 male subjects aged 20 to 30 participated in this experiment.

The other condition and methods are the same as the experience 1.

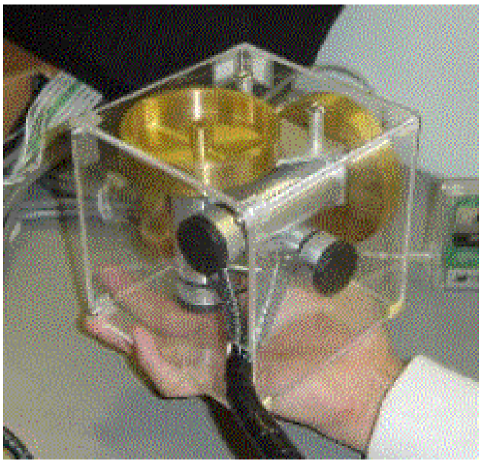
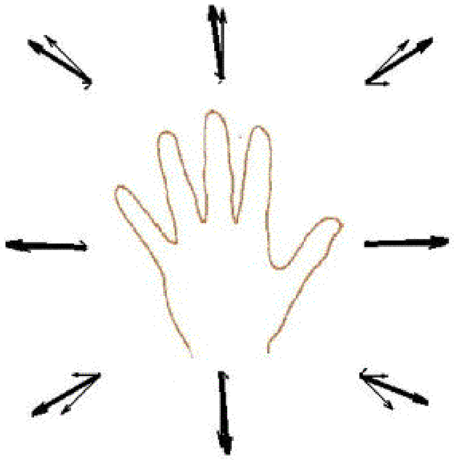


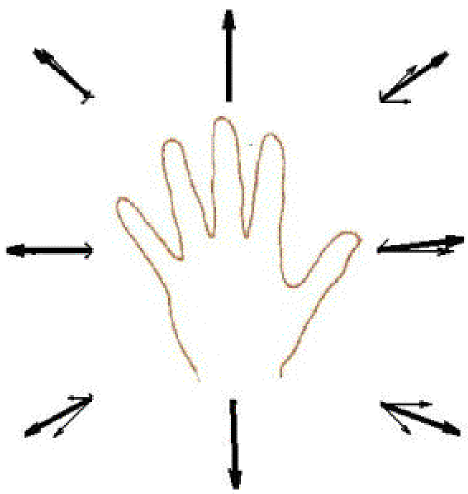
Fig. 7 Rotated 90 degrees around the normal of the palm

5.3 Results and Discussions

Figure 8 plots the perceived directions and the number of subjects who felt that direction as thin vectors, for each direction of presented torque as well as experiment 1. According to these results, there is no significant difference in the way of grasping the device. This means this device manufactured so symmetrically that we can perceive the same torque irrespective of the way of grasping and the cable doesn't influence the results of the previous experiment and this ones.



(a) pattern 1



(b) pattern 2

Fig. 8 Variation of perceived direction 2

6. Conclusion

In this paper, to inform a constant direction continuously by haptic device "GyroCube", the new haptic display method was proposed and the accuracy and threshold of the method were verified by subjective experiments. The results are the followings. There was no significant difference between weaker resetting torque and stronger resetting torque. The threshold of sensitivity was approximately 200 [gfcm] in either hand. There was no significant difference in the way of grasping this device. The way of grasping doesn't influence the result of the correction, accuracy, and threshold. One of the applications of such device would be, for example, the game of fishing installing "CyroCube" in the fishing rod or a haptic navigator for pedestrians and so on. But "GyroCube" was so heavy and big for a palm. Now we are developing a new torque display that is lighter and smaller than "GyroCube".

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