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Mobile Torque Display and Haptic Characteristics of Human Palm

Yokichi Tanaka*1, Sakai Masataka*1, Kohno Yuka*1, Yukio Fukui*1*2
Juli Yamashita*2, Norio Nakamura*2
*1: University of Tsukuba,
1-1-1, Tennoudai, Tsukuba, Ibaraki 305-8573, Japan
*2: National Institute of Advanced Industrial Science and Technology
1-1, Higashi, Tsukuba, Ibaraki 305-8566, Japan
fukui@is.tsukuba.ac.jp

Abstract

A portable or mobile force feedback device needed to have a support of reactive force on the body, or body grounding in order to realize its portability. The body grounding, however, makes force feedback loop within the body and device themselves, resulting in being unable to present an external force to the user. This paper reports an experiment using a new portable device that presents an external torque to the user without any grounding means. By using this device, some characteristics of human palm were obtained. For example, if a torque stimulus was presented to a diagonal direction of one's palm, one tends to misperceive it as a stimulus of rolling direction rather than that of pitching direction.

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

1. Introduction

From the early days of virtual reality technology, a force feedback device is thought to be an essential tool to explore and manipulate virtual objects in the virtual world. Many researches have been done on this topic, and many kinds of force feedback devices have been developed up to today. A force feedback device, in principle, must have some basis to support its reactive force. We call this supporting of the reactive force "*grounding*"[1] in this paper. Force feedback devices are classified into two categories according to their grounding means, or portability: *body grounding*, and *earth grounding*. Table 1 shows some examples.

There are various machines using various mechanisms and methods to present force based on the earth grounding. In this case the operation are limited to the area of working ranges of the mechanisms of the devices. To overcome this difficulty, body-grounding type devices have been proposed. This portable virtual environment technology is a recent trend for extending and merging the virtual world into real space. The downsizing of computers and their interface devices has spurred this tendency.

Rutgers Portable Master [1] presents grasping power to the fingers using air cylinders, the basis of which is the palm. HapticGEAR [2] using wires for presenting force to the arm makes use of user's back as the basis, and a haptic joystick [3] uses the operator's arm as well. However, because the haptic sensation of these devices is given as an internal force within the human body, there occurs a problem that the operator cannot adequately feel an external force, that is, a force as if it was presented from an external object. The force display using gyro moment [4] is a non-grounding type one.

This study proposes a new mobile type torque feedback device without grounding, and shows the details of a psychophysical experiments using the device on how people can feel the torque presented on their palms.

Table 1: Classification of haptic devices (modified from [3])

	Exoskeleton type	Tool grasping type
Earth grounding type	SARCOS Master EXOS Arm Master etc.	Haptic Master PHAMToM SPIDAR etc.
Body grounding type	Rutger Master CyberGrasp CyberTouch etc.	HapticGEAR HapticJoystick etc
No grounding type		Gyro moment display **proposed GyroCube**

2. System Configuration

2.1 Design Policy

A torque-feedback device that can be used at any place must be of a type that is not grounded or fixed to something but can be carried around freely. Therefore, the aim of the research is to develop a portable and mobile torque-feedback device that can present an external force and apply it to palm top display. Now that the torque is the time differential of angular momentum, the device is designed to pick out the torque using the law of conservation of angular momentum, during the change of the angular momentum of the rotor by controlling the current into the motor. Therefore, what the device presents to the user is an external torque, not an external force.

To present an external torque using the change of angular momentum repeatedly, it is necessary for the rotor to return to the initial state periodically. In short, angular momentum vector L needs to have a closed locus. In this case however, it is difficult to keep the torque vector in a constant direction for a long time, because the rotor cannot be accelerated too much. Thus, it is designed to generate a strong torque for a short time toward the desired direction, and a weak one for a long time toward the opposite direction in order to return the rotor to the initial state. The user is expected to feel mainly the strong signal and ignore the weak one due to the human perceptive characteristics.

2.2 Method of Torque Presentation

A device named GyroCube is developed [5] and is shown in **Fig.1**. In order to change the angular momentum in arbitrary orientation in 3D space without rotating the rotation axis of the motor, three motors were arranged orthogonal with each other. By controlling acceleration and deceleration of rotation of each motor independently, three angular momentum vectors are added into a vector, presenting an arbitrary magnitude and orientation. See **Fig 2**. Wheels of large moment of inertia are installed in the axes of motors in order to obtain stronger torque. The size and weight of the device are approximately 12 cm^3 and 2 kg respectively. A driver and a DA conversion board are installed at the controlling unit.

The torque, that is the change of angular momentum, is expressed with the following formula:

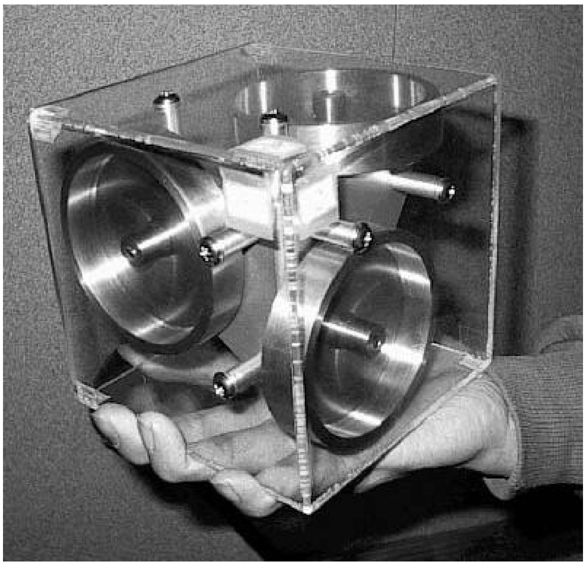


Fig.1 Developed Torque feedback device GyroCube

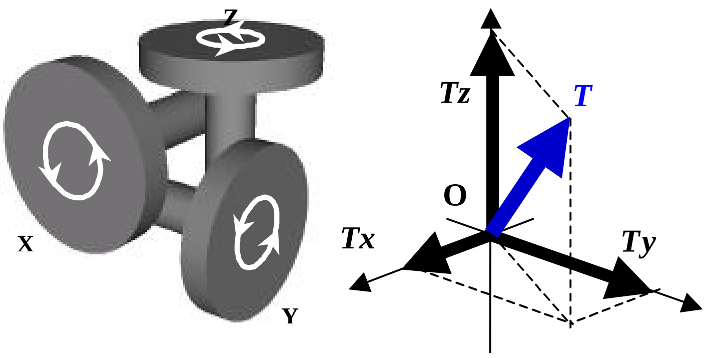


Fig.2 Addition of component angular momentum vectors

$T = dL/dt, \quad dL = I\,dw$

Where,

T :torque [N•m]

dL: change of angular momentum [kg•m²/s]

dt : change of time [s]

I : moment of inertia [kg•m²]

dw:change of angular speed [l/s]

The moment of inertia of the wheel is $2.3*10^{-4}$[kg*m²]. For example, if a torque of 600[gf*cm] is generated for 1.0 second from the initial resting state, the wheel reaches approximately 2,440[rpm] after a second. As the total angular momentum is constant at any time, then the torque of the same magnitude but opposite direction would be output based on the law of action and reaction, or the law of conservation of angular momentum.

3. Experiment

3.1 Purpose

As this device is a mobile type, it is promising to be applied into our daily life. The purpose of the following experiment is to make this device utilized in practical use. Designing a device for an application such as portable navigation needs perceptive characteristics obtained when it is grasped by hand. It is well known that the distribution density of mechnoreceptor differs according to the location on the hand. Thus, in order to clarify the difference in sensitivity depending on the location of the hand, an experiment was conducted by using torque output of eight different directions. In short, this experiment was carried out focusing on the following matters:

(1) Is the torque perceived differently on the palm, when the presented torque is in different directions?

(2) Is there any difference of sensed torque between the right hand and the left?

3.2 Experimental Design

[Conditions]

(1) First, we made torque stimuli design by a combination of the following conditions, and then created a randomized stimulation sequence:

-Control voltage: (4.0 and 2.8)[Volt]
equivalent torque is 720g*cm, 504g*cm respectively.

-Presenting time: 0.40[second]

-Presenting directions: eight directions (North, South, East, West, NorthEast, SouthEast, SouthWest, and NorthWest). Hereafter we abbreviate southwest as SW, south as S and so on.

(2) Eight directed stimuli were presented repeatedly six times. Three of them were strong signals, and the other three were weak. Total 48 torque stimuli were presented for each palm, the right and the left.

[Methods]

A Subject put his right or left arm on the table while seated on a chair, and held the device with either one of their palms so that the wrist could move freely.

To make the subject concentrate on haptic sensation visual information was shut out by covering the device with a cloth. The subject was asked to answer the directions (among eight directions) as he felt, after each torque stimulus was presented.

[Subjects]

Total 10 male and female subjects aged 20 to 30 participated in this experiment. Nine of them were right-handed and one left-handed.

3.3 Results and Discussions

(1) Correct answer ratio and misperception classified by directions

Table 2 shows the predominant answer ratio of specified direction, whether correct or incorrect, for presented stimulus direction.

[Diagonal Directions: SW, SE, NW and NE]

-When the device presented torque stimulus in diagonal directions (SW, SE, NW and NE) to the subjects they tend to answer a rolling direction (W or E). (Ex. When the correct answer would be SW or NW, they tend to answer W, and when the correct answer is SE or NE, they tend to answer E.)

[Pitching Directions: N and S]

-When the device presents torque stimulus in pitching directions (N or S), they tend to answer one of the neighbor directions. (Ex. When the correct answer is N, they tend to answer NW or NE.)

[Rolling Directions W and E]

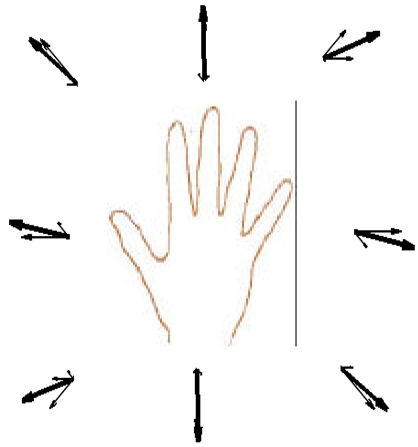
-If we focus on direction W and E, the correct answer ratio of W is higher than E in the left hand, while that of E is higher than W in the right hand. These results are symmetrical. Certainly hands are likely to turn easily to the inward. But these data show that it doesn't mean hands are more sensitive to inward than to outward. It seems that the inward torque (for the left palm E-direction, for right W-direction) is likely to be perceived more variedly than outward torque (for the left palm W, for right E). If the perceived torque were varied as seen in the experiments, it would be hard for the subjects to tell the correct direction. But if the perceived torque doesn't vary or disperse (as outward directed torque) so much, then the subjects would sense the stimuli confidently, and they could answer the correct direction. This characteristic is obvious in the right hand. The variation or dispersion of the perceived torque direction can be seen in **Fig. 3.**

Table2 Answer ratios of correct and incorrect direction for each palm

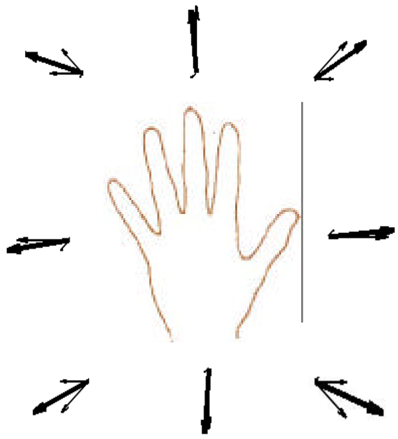
Left palm		Right palm	
Answer for SW		Answer for SW	
SW	50.0	SW	54.6
W	32.4	W	38.9
NW	13.0		
Answer for S		Answer for S	
S	75.9	S	75.0
SE	10.2	SW	8.3
SW	8.3	SE	2.8
Answer for SE		Answer for SE	
SE	71.3	SE	50.0
E	18.5	E	36.1
S	4.6	NE	6.5
NE	3.7		
Answer for W		Answer for W	
W	70.4	W	73.1
NW	25.0	SW	18.5
SW	3.7		
Answer for E		Answer for E	
E	69.4	E	82.4
SE	27.8	NE	12.0
		SE	4.6
Answer for NW		Answer for NW	
NW	77.8	W	46.3
W	15.7	NW	41.7
N	3.7	SW	7.4
Answer for N		Answer for N	
N	75.0	N	82.4
NW	12.0	NW	11.1
NE	9.3		
Answer for NE		Answer for NE	
NE	47.2	NE	64.8
E	44.4	E	26.9
SE	6.5		

[Gap between the presented and perceived torque directions]

The figure 3 shows the gap between the direction of the presented and perceived torque stimuli for each direction. In the figure, the correct or incorrect answer ratio of each direction of perceived torque is shown as a vector. The length of each arrow shows the answer ratio according to Table 2, while the thick arrow shows the addition of thin vectors. We can see that the thick arrows are the mean direction that subjects statistically feel.



(a) Left palm



(b) Right palm

Fig. 3 Variation of perceived direction

(2) Comparison of the sensation of torque direction between left and right palms

[Comparison using Table 3]

At a first glance of **Table 3**, they seem to have no predominant characteristics. However there exists an interesting result. The average of the correct answer ratio for the left palm is 67.7, while that of the right palm is 66.1. The averages are close to each other. Though both palms have certainly their own differences in sensitivity according to the location on the palm, this result proves that the overall average sensitivities of both palms are almost the same. Moreover the areas of the two charts are almost the same too. At first we thought right-handers' right hands are more sensitive than their left ones. But this result reveals that it is not true, and that haptic sensitivity of palms does not depend on right-handed or the left-handed.

Table 3 Direction ranking for the correct answer ratio

Left palm		
Ranking	Direction	Ratio
1st	NW	77.7
2nd	S	75.9
3rd	N	75
4th	SE	71.3
5th	W	70.4
6th	E	69.4
7th	NE	51.9
8th	SW	50

Right palm		
Ranking	Direction	Ratio
1st	N	82.4
1st	E	82.4
3rd	S	74.1
4th	W	73.1
5th	NE	64.8
6th	SW	55.6
7th	SE	50
8th	NW	46.7

[Comparison using radar charts]

Two radar charts are made from the data of Table 3**.** and illustrated in **Fig. 4** The shapes of the two charts are similar. They are roughly symmetrical. This result indicates that the perceptive characteristics of directions of both palms are symmetrical. The both shapes are dented ellipses, and the direction of longer axes are oblique and rather toward vertical than toward horizontal. This means that people are apt to misperceive the direction more toward pitching direction than toward rolling direction if the oblique stimulus torque is applied.

[Total data]

Four dominant directions those are N, E, S, and W have higher correct answer ratio than those of diagonal directions NE, NW, SE and SW (See **Table 4** and **Fig. 5**). This implies that man is apt to feel the direction of torque stimulus toward one of four dominant directions. Figure 5 shows the chart is line symmetrical both vertical and horizontal lines. In the experiments, most of the subject are right-handed and this means that there exists no unsymmetrical characteristics of direction perception for the right-handed people.

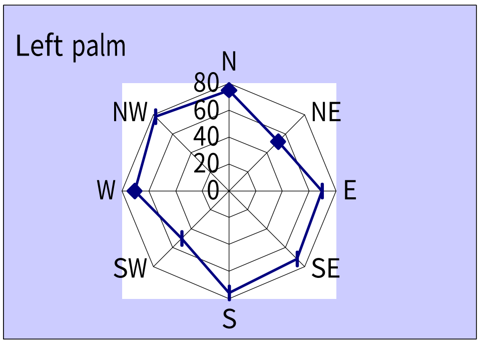
4. Summary

This study proposed a mobile type torque-feedback device named GyroCube that generates an external force. Through the experiment, the following perceptive characteristics of palms were obtained.

1. There is no difference in the total sensitivity of the right palm and the left.

Table 4: Ranking of average correct answer ratio for both palms

Average of both palms		
Ranking	Direction	Ratio
1st	N	78.7
2nd	E	75.9
3rd	S	75
4th	W	71.8
5th	SE	60.6
6th	NW	59.7
7th	NE	58.3
8th	SW	52.8



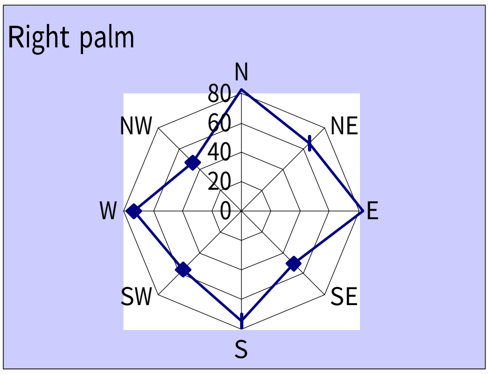


Fig. 4 Correct answer ratios of each palm for eight directions

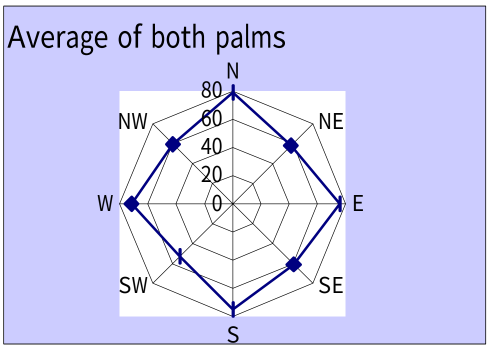


Fig. 5 Average correct answer ratio of both palms

2. Palms turn around easily to inwards than to outwards,

while people are more sensitive against outward directed stimulus rather than inward one.
3. If a torque stimulus is presented to a diagonal direction, people tend to misperceive it as a rolling stimulus rather than a pitching one.
4. People are apt to perceive dominant orthogonal four directions, those are north, south, east, and west, better than other diagonal directions.
5. Accounting for the results of the experiments, it is suggested that torque display for palm can be designed to make the correct answer ratio higher and almost the same in any direction by adjusting the magnitude of presenting torque of each direction.

The application of this device would be, for example, a haptic navigator. It can also be used for amusement such as game interfaces. For practical use, following problems remain:
-To develop a system that works with a position detection mechanism.
-To improve portability by incorporating the control portion into the frame.
-To improve the mechanism, which would make the operator being able to grasp a location nearer the center of gravity.
-To investigate human perceptive characteristics in more detail.
- To redesign it smaller and lighter.

References

1. Grigore C. Burdea: Force and touch feedback for virtual reality, John Wiley & Sons, Inc., 1996.

2. M. Hirose, T. Ogi, H. Yano, N. Kakehi: Development of Wearable Force Dispaly (HapticGEAR) for Immersive Projection Displays, *Proc. IEEE Virtual Reality*, 79, 1999.

3. H. Iwata, H. Nakagawa: Wearable Force Feedback Joystick, *Human Interface N&R*, 13, 2, pp.135-138, 1998 (in Japanese).

4. Y. Masayuki, H. Yano, H. Iwata: Development of Non-grounded Force Display Using Gyro Moment, *Human Interface N&R*, 3, 1, pp.25 -30, 2001 (in Japanese).

5. K. Nakata, N. Nakamura, J. Yamashita, S. Nishihara, Y. Fukui: Torque-feedback device using angular momentum transition, Trans. of Virtual Reality Society of Japan, 6, 2, 115-120, 2001 (in Japanese).