Development of a Wrist-Twisting Haptic Display Using the Hanger Reflex

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ABSTRACT

The hanger reflex is a strong force illusion that was previously known to occur in the human head. We applied the hanger reflex to the wrist and had expected that "sweet spots" would exist for the hanger reflex at the wrist, similar to the properties of the hanger reflex at the head. By measuring the pressure distribution and the rotation angle when the hanger reflex device was attached to the wrist, we found "sweet spots" that efficiently generate the hanger reflex at the wrist. Based on the pressure distribution obtained, we developed a device to control hanger reflex generation at the wrist. This device reproduces the pressure distribution by pressing on the hanger reflex "sweet spots" using four linear actuators, and thus generates the hanger reflex at the wrist. The results of user testing indicated that the device can produce rotational forces efficiently.

Author Keywords

Pseudo-force; hanger reflex; pressure distribution; haptic display.

ACM Classification Keywords

H.5.2 [Information Interfaces and Presentation]: User Interfaces −*Haptic I/O*

INTRODUCTION

Recent advances in computer entertainment, such as Microsoft's Kinect and the Nintendo Wii balance board, have enabled users to interact with computer-generated worlds through whole-body motion. However, these interactions lack haptic cues, particularly the force feedback cue, largely because the provision of conventional force feedback would require a large space and high costs.

This paper presents a solution to this issue based on the use of the hanger reflex, which is a strong rotational force illusion, at the wrist. The hanger reflex is a phenomenon where the human head feels a rotational force when a wire hanger is wrapped around the temporal region of the head [11]. While the hanger reflex was previously known to occur in the human head, we discovered that the phenomenon also occurs at the wrist [12]. In this paper, to establish more efficient hanger reflex generation at the wrist, we conducted an experiment to find "sweet spots" for the hanger reflex at the wrist. We also developed a device that controls the occurrence of the hanger reflex efficiently at the wrist by pressing these sweet spots.

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RELATED WORK

There have been several previous devices that have attempted to let users feel forces in compact spaces, which can be roughly divided into two types.

The first is the portable type device, where the users grasp the device with their hands. Tanaka et al. [1] and Winfree et al. [2] both used the gyro effect to present rotational forces, while Amemiya et al. [3, 4] used asymmetric acceleration. Recently, Rekimoto et al. [5] showed that a relatively high frequency asymmetric vibration induces similar effects, and achieved a much more compact system. While these devices can present both translational and rotational forces, the users must hold the device continuously, and this is not generally suitable for interaction with virtual fields.

The other device type is the wearable device, meaning that the users do not need to hold the device continuously. Yang et al. [6] developed a seven degrees-of-freedom (7-DOF) wearable haptic device, Letier et al. [7] developed a portable arm exoskeleton, and Tsetserukou et al. [8] presented a force to the forearm by winding a belt bridging between the user's upper arm and forearm. While these devices can present real forces, there is still room to improve them for greater simplicity and lower costs.

One solution to this issue is to use the pseudo-force induced by skin stretching. Minamizawa et al. [9] developed the gravity grabber, which is a finger-mounted device containing two direct current (DC) motors and a belt. Massimiliano et al. [10] developed a haptic device to present the low frequency component of friction using a shape memory alloy (SMA). These all works succeeded in presenting the sensation of a force at the user's fingertips by tangential skin deformation. A similar principle was also applied at the forearm. Berk et al. [13] presented directional information by pinching the skin of the forearm. Kuniyasu et al. [14, 15] stretched the forearm skin to induce the sensation of translational motion. These skin-stretching-type wearable devices are ideal for computer entertainment applications because they do not limit or inhibit the actions of the users. However, in their current state, the forces that can be induced by these devices are not sufficiently striking to be used for computer entertainment purposes.

However, we have observed one strong pseudo-force perception phenomenon, called the hanger reflex [11]. The hanger reflex is a phenomenon where the head feels a rotational force when a wire hanger is wrapped around the temporal region of the head (Figure 1). The conventional hanger reflex device for the head is made from a medical plastic cast based on the shape of the user's head [16]. This shape can press on the hanger reflex "sweet spots" and generate the hanger reflex efficiently. While the hanger reflex is considered to be a pseudo-force illusion induced by skin stimulation, the force is strong enough to change the user's head posture, and users typically describe the force as "irresistible" (although they actually can resist this force illusion). Sato et al. [17] measured the pressure distribution around the human head to find the "sweet spots" for the phenomenon.

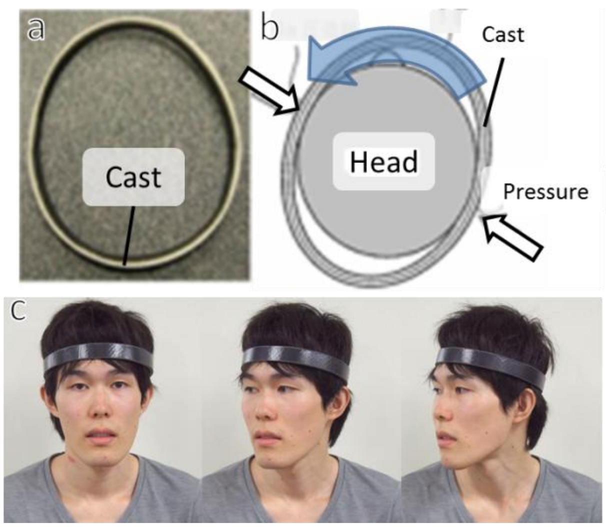

Figure 1. Conventional device for hanger reflex [16].

While the hanger reflex had only previously been observed at the head, we have discovered that this phenomenon occurs in other parts of the body, including the wrist and the waist [12]. Figure 2 shows the structure of the device used for this effect on the wrist. The device is shaped to press upon the wrist when the device is rotated. In addition, urethane foam was placed inside the device to reduce any pain caused by the pressure applied by the device. However, the "sweet spot" for the hanger reflex at the wrist was not fully explored.

EXPERIMENTAL

Measurement System

We had expected that "sweet spots" would exist for the hanger reflex at the wrist, similar to the properties of the hanger reflex at the head. To locate these spots, we measured the pressure distribution at each participant's left wrist using a pressure sensor array (FSR 400, Interlink Electronics) (see Figure 3).

The angle of rotation of the wrist caused by the hanger reflex is measured using a Leap Motion device (Leap Motion Inc.) (Figure 3), which is placed inside a box. The arms of each participant are inserted into this box. The measurement system obtains both the pressure distribution and the angle of rotation simultaneously.

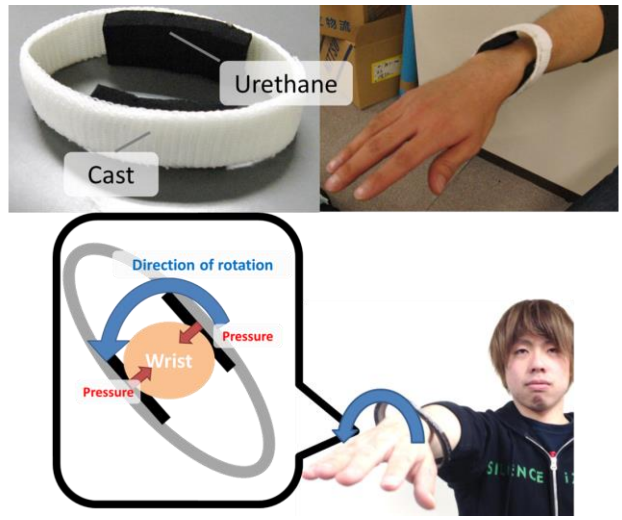

Figure 2. Structure of the hanger reflex device for use at the wrist [12].

Procedure

Four participants (age range of 22-29 years, all male laboratory members) took part in the experiment. In a preliminary test, all participants confirmed that the hanger reflex was elicited at their wrists by the device. The number of sensors used in the pressure sensor array depends on the size of the individual's wrist, but in this case, all participants coincidentally had similar wrist sizes, so we used 22 pressure sensors for all participants.

After the sensor array was installed around the participant's wrist, the hanger reflex device was placed on the wrist from above. The experimenter then turned the device by 8 mm (the spacing interval of the pressure sensor array) for each measurement. The participants were instructed to stand close to the measurement system, and to keep opening their left hand during the measurement process. They were also asked not to resist the rotational force if they felt the rotational force induced by the hanger reflex. The measurements were performed 11 times (22/2=11), so that the device rotated halfway around the wrist.

After the pressure distribution and rotation angle data for the wrist were obtained, the data were processed as follows. First, the values obtained for each participant were divided into two groups: left turn and right turn values. In each group, the weighted sum of the pressure distribution was calculated as follows:

$$\mathbf{P_r} = \sum_{i:trials\ of\ right\ turn} r_i \mathbf{P_i}$$

where i is the number of trials for right (or left) turns, r_i is the rotation angle, and P_i is the force distribution. The resulting force distribution was then normalized from 0 to 1, and the results for all participants were averaged.

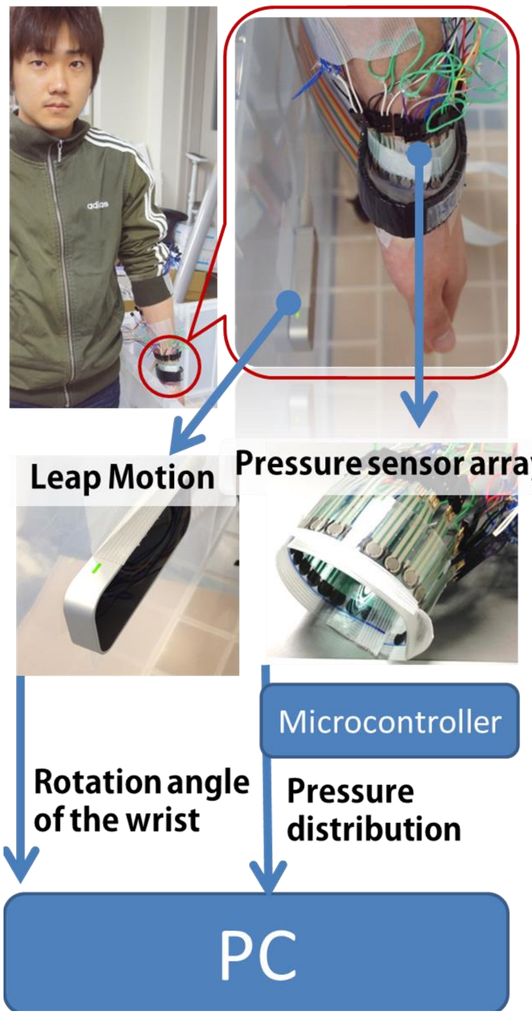

Figure 3. Measurement system used for the pressure distribution at the wrist

Results

Figure 4 and Figure 5 show the radar charts obtained by the measurement process. Figure 4 shows the left rotation results, and Figure 5 shows the right rotation results. The numbers on the circumferences of the charts indicate the sensor numbers, and the radius indicates the level of contribution to the rotation, where a larger radius value indicates a higher contribution to the rotation.

Based on these charts, the pressures from sensor 18 and sensor 7 contribute to the left rotation. Sensor 7 is located outside the radial bone on the back of the hand, and sensor 18 is located outside the ulna, which is near the root of the little finger (Figure 6). However, the pressures from sensor 15 and sensor 5 contribute to the right rotation. Sensor 5 is located outside the radial bone at the root of the thumb, and sensor 15 is located outside the ulna on the back of the hand (Figure 6).

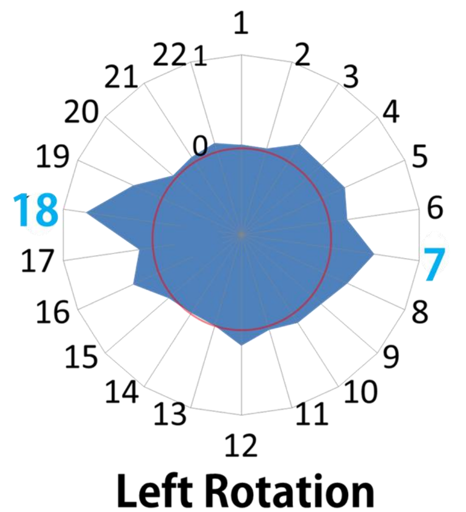

Figure 4. The pressure distribution contributing to the left rotation of the wrist.

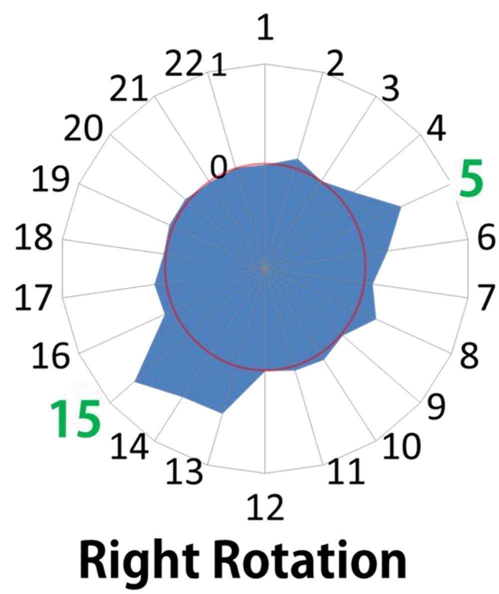

Figure 5. The pressure distribution contributing to the right rotation of the wrist.

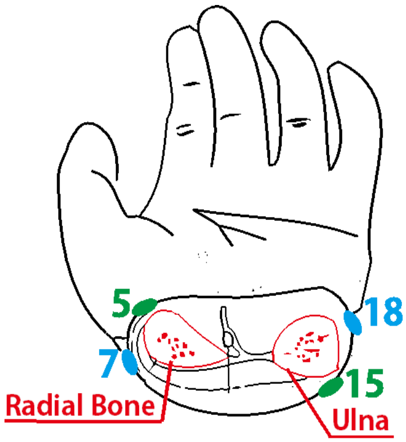

Figure 6. Sweet spots for the hanger reflex at the wrist.

WRIST-TWISTING HAPTIC DISPLAY

Based on the pressure distribution that was measured in the previous section, we developed a device to control the generation of the hanger reflex at the wrist. The device reproduces the pressure distribution by pressing on the "sweet spots" for the hanger reflex using four linear actuators (Miniature Linear Motion series PQ12, Firgelli Technologies Inc.), and thus generates the hanger reflex at the wrist (Figure 7). For safety, the force sensors (FSR 400) that are attached at the tips of the linear actuators limit the force. The users can control both the left and right turns of the wrist using this device.

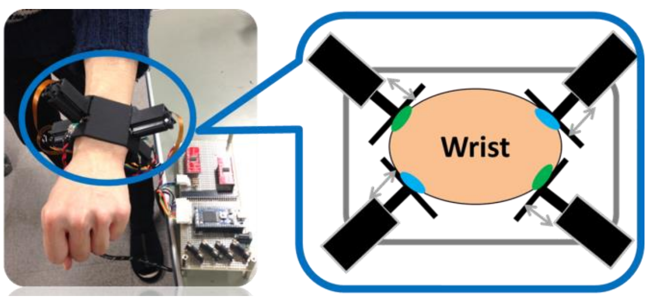

Figure 7. The mechanism of the wrist device.

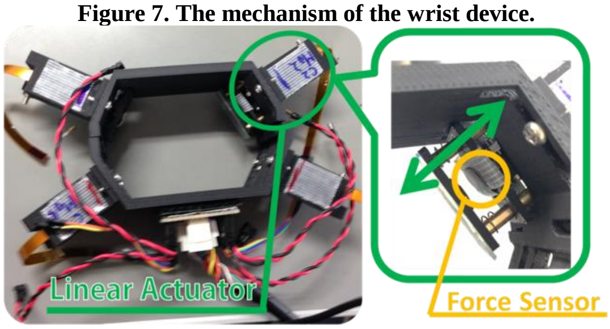

Figure 8. The wrist device pressing mechanism.

User Test

We recruited three members of our laboratory for the preliminary evaluation. Two of the three had been participants in the previous experiment. We asked each participant to wear the device and controlled the actuators to apply the appropriate pressure distributions for both left and right rotations.

All subjects answered the questions about the directions in which the forces were felt correctly, which indicates that the device succeeded in both controlling and presenting the rotational force. The participants' comments included "my arm was squeezed" and "my arm seemed to rotate continuously". The two subjects who had participated in the previous experiment both commented that "the force that I felt was similar to that of the previous experiment, but the magnitude of the force was greater". This comment indicates that we achieved efficient hanger reflex generation at the wrist by pressing on the sweet spots.

Figure 9. Overview of the experiment in the left rotation case.

CONCLUSIONS AND FUTURE WORK

This paper reported the conditions required for generation of the hanger reflex at the wrist, and the development of a device to generate the hanger reflex at the wrist based on these conditions. By measuring the pressure distribution and the rotation angle when the hanger reflex device was attached at the wrist, we found pressure points that can efficiently generate the hanger reflex at the wrist. Using linear actuators to press on these points, we developed a device to control hanger reflex generation at the wrist. The results of user testing indicated that the device can present rotational forces efficiently.

Our future work includes the development of applications using this device. One possible application is the human puppet as shown in Figure 10. The rotational angles of a human and a puppet are synchronized using the device, so that the puppet functions as an avatar robot of the user. When the operator moves the wrist of the puppet, the user feels as if his/her arm is being twisted. The puppet can be replaced by a character in the virtual world, and the player can then interact with the character in the virtual field through the wrist-twisting device. We also aim to extend this experience to the whole body by exploring the occurrence of the the hanger reflex at other parts of the body.

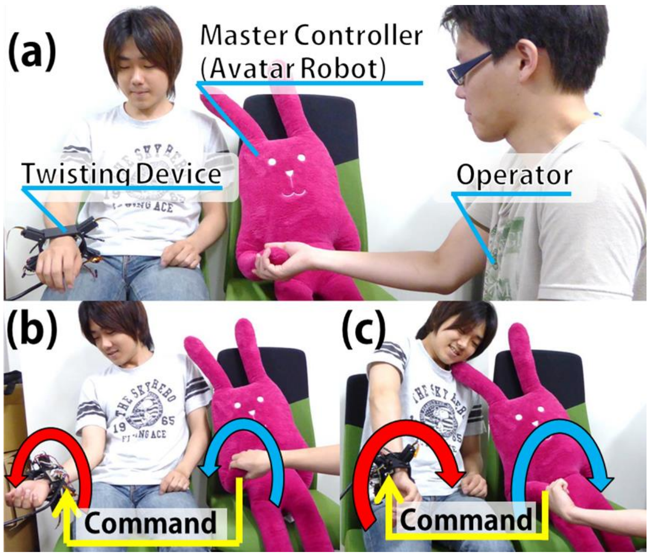

Figure 10 Concept image for the human puppet application. (a) Setup for the human puppet. Following a cue from the operator, the avatar robot twists the wrist of the wearer (b) to the left and (c) to the right.

REFERENCES

1. Tanaka, Y., Sakai, M., Khono, Y., Fukui, Y., Yamashita, J. and Nakamura, N. Mobile torque display and haptic characteristics of human palm. In *ICAT 2001* (2001), 115–120.

2. Winfree, K.N., Gewirtz, J., Mather, T., Fiene, J. and Kuchenbecker, K.J. A high fidelity ungrounded torque feedback device: The iTorqU 2.0. In *Proc. EuroHaptics 2009*, IEEE(2009), 261–266.

3. Amemiya, T., Ando, H. and Maeda, T. Phantom-DRAWN: direction guidance using rapid and asymmetric acceleration weighted by nonlinearity of perception. In *Proc. 2005 Int. Conf. Augmented Tele-existence*, ACM Press (2005), 201–208.

4. Amemiya, T., Ando, H. and Maeda, T. Directed force perception when holding a nongrounding force display in the air. In *Proc. EuroHaptics*, IEEE(2006), 317–324.

5. Rekimoto, J., Traxion: a tactile interaction device with virtual force sensation. In *Proc. 26th ACM Symp. User Interface Software and Tech*. ACM Press (2013), 427–432.

6. Yang, G., Ho, H.L., Chen, W., Lin, W., Yeo, S.H. and Kurbanhusen, M.S. A haptic device wearable on a human arm. In *2004 IEEE Conf. Robotics, Automation and Mechatronics*, IEEE (2004), vol. 1, 243–247.

7. Letier, P., Avraam, M., Veillerette, S., Horodinca, M., De Bartolomei, M., Schiele, A. and Preumont, A. SAM: A 7-DOF portable arm exoskeleton with local joint control. In *2008 IEEE/RSJ Int. Conf. Intell. Robots and Sys*, IEEE/RSJ (2008).

8. Tsetserukou, D., Sato, K. and Tachi, S. FlexTorque: Exoskeleton Interface for Haptic Interaction with the Digital World. In *Haptics: Generating and Perceiving Tangible Sensations* (2010), 166–171.

9. Minamizawa, K., Prattichizzo, D. and Tachi, S. Simplified design of haptic display by extending one-point kinesthetic feedback to multipoint tactile feedback. In *IEEE Haptics Symp*., IEEE (2010), 257–260.

10. Solazzi, M., Provancher, W.R., Frisoli, A. and Bergamasco, M. Design of a SMA actuated 2-DoF tactile device for displaying tangential skin displacement. In *IEEE World Haptics Conf. (WHC),* IEEE (2011), 31–36.

11. Matsue, R., Sato, M., Hashimoto, Y. and Kajimoto, H. "Hanger reflex": A reflex motion of a head by temporal pressure for wearable interface. In *SICE Ann. Conf.* IEEE (2008), 1463–1467.

12. Nakamura, T., Nishimura, N., Sato, M. and Kajimoto, H. Application of hanger reflex to wrist and waist. In *IEEE Virtual Reality (VR)*, IEEE (2014), 181–182.

13. Bark, K., Savall, J., Cutkosky, M., Wheeler, J. and Lee, G. A wearable skin stretch device for haptic feedback. In *IEEE World Haptics Conf.*, IEEE (2009), 464–469.

14. Kuniyasu, Y., Fukushima, S., Furukawa, M. and Kajimoto, H. Weight illusion by tangential deformation of forearm skin. In *Proc. 2nd Augmented Human Int. Conf.*, ACM Press (2011), 10.

15. Kuniyasu, Y., Sato, M., Fukushima, S. and Kajimoto, H. Transmission of forearm motion by tangential deformation of the skin. In *Proc. 3rd Augmented Human Int. Conf*., ACM Press (2012), 16.

16. Asahi, T., Sato, M., Kajimoto, H., Oyama, G., Taira, T., Hayashi, A., Fujii, M. and Takashima, S. Clinical Multicenter Trial For The Treatment Of Cervical Dystonia Using The Hanger Reflex: Interim Report. *Stereotact Funct. Neurosurg. 91*, suppl. 1 (2013), 165.

17. Sato, M., Matsue, R., Hashimoto, Y. and Kajimoto, H. Development of a head rotation interface by using hanger reflex. In *18th IEEE Int. Symp. Robot Human Interact. Comm. (RO-MAN)*, IEEE (2009), 534–538.