Transmission of Forearm Motion by Tangential Deformation of the Skin

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ABSTRACT
When teaching device handling skills such as those required in calligraphy, sports or surgery, it is important that appropriate arm motion is transmitted from the trainer to the trainee. In this study, we present a novel, wearable haptic device that produces arm motion using force sensation. The device produces skin deformation and a pseudo-force sensation that is similarly to the force produced when the arm is "pulled". The device generates skin deformation in four directions, and in this paper we have evaluated the device using a directions perception experiment.

Categories and Subject Descriptors
H5.2. INFORMATION INTERFACES AND PRESENTATION: User Interfaces – haptic I/O, prototyping.

General Terms
Performance, Experimentation, Human Factors

Keywords
Pulling arm, forearm skin, force sensation

1. INTRODUCTION
When teaching device handling skills such as those required in calligraphy, sports or surgery, it is important that appropriate arm motion is transmitted from the trainer to the trainee. Trainers typically teach skilled movement using two methods. Firstly, they provide a visual demonstration of the movement and secondly they may hold the trainee's hand and haptically (using tactile feedback) demonstrate the motion. Using visual demonstrations, such as videos, allows multiple users to observe and learn skills, however, individual attention, feedback and insight regarding the movement is limited. The haptic method, allows the trainee to receive immediate feedback regarding errors, however, only one trainee can be trained at a time by a single trainer.

To solve this problem, many methods have been proposed to train motion using haptic cues. These methods can be categorized into two types.

The first type uses vibrotactile sensation. Sergi et al. developed a vibrotactile wristband (with four vibrators around the band) to guide the motion of the forearm [1]. Lieberman et al. developed a vibrotactile "suit" to guide the joint motion [2]. These methods are simple; however, users must interpret the direction of motion by the position of the vibrotactile stimulation. This reduces their insight regarding the movement.

The second type uses force sensation to train motion. Henmi et al. developed a calligraphy motion training method using a force sensation haptic device [3]. Feygin et al. developed a perceptual motor skills training method using a force sensation haptic device that was evaluated using a trajectory tracking task [4]. These methods are intuitive to the trainee as they are not required to interpret the stimulation because the motion is presented to them directly by the device. However, most of them require a grounded haptic device like a PHANToM [5], which limits application areas.

We have developed a wearable haptic device that produces a force sensation that can be used for training hand motion. Unlike grounded haptic devices, it is difficult to produce external forces using a wearable haptic device. Therefore, we have developed a device that produces the illusionary sensation of external force. This "illusion" is generated through skin deformation. Through producing an illusory force sensation via simple skin deformation our device is able to guide motion.

The illusory sensation used in our device is the "pulling arm" sensation produced by tangential skin deformation of the forearm. The "pulling arm" is a typical guiding movement used when teaching hand skills such as those used in calligraphy. In previous work we demonstrated that a pseudo-force sensation caused a "pulling arm" force in a weight comparison task [6].

In this paper, we have extended our previous design and have developed a device that produces pseudo-forces in four directions, forward, backward, right and left. We have also evaluated the system using a directions perception experiment.

2. RELATED WORKS
A few handheld devices that produce pseudo-force sensations have been developed. Based on the nonlinearity of human perception, Amemiya et al. developed a device that used asymmetrical vibration to produce a pseudo-force sensation [7].

AH '12, March 08 - 09 2012, Megève, France
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Yano et al. developed a device that produced a torque sensation utilizing the gyro effect [8].

Previous work has also proposed “wearable” but not “portable” devices that stimulate the skin to produce a pseudo-force sensation. Minamizawa et al. [9] and Inaba et al. [10] proposed devices that squeezed the skin of a finger to produce the pseudo-force sensation. Shull et al. [11] produced tangential skin deformation on the arm with the primary purpose to emphasize the direction of arm joint rotation.

Our work can be considered a development of these prior attempts to produce a pseudo-force sensation by skin deformation. Previously we demonstrated that we could produce a pseudo-force sensation by causing tangential skin deformation on the forearm using a simple haptic device [6](Figure 1).

While our previous device could produce pseudo-force sensation in two directions (up and down), practical hand-skill training scenarios, specifically calligraphy, require a large range of movement in four directions (forward, backward, right and left) and relatively small range of motion in the remaining two directions (up and down). Therefore, this work focuses on the design and evaluation of a device that produces skin deformations that cause the production of pseudo-force sensations in four directions, forward, backward, right and left.

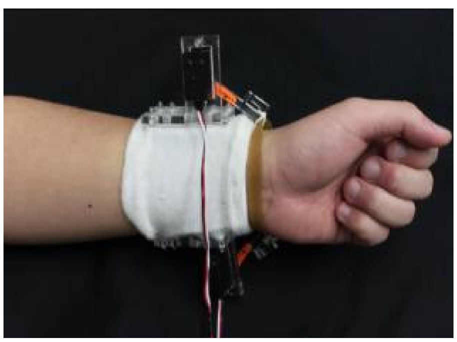

Figure 1: Pseudo-force sensation produced by tangential skin deformation [6].

3. DEVICE DESIGN

Figure 2 shows an overview of our device.

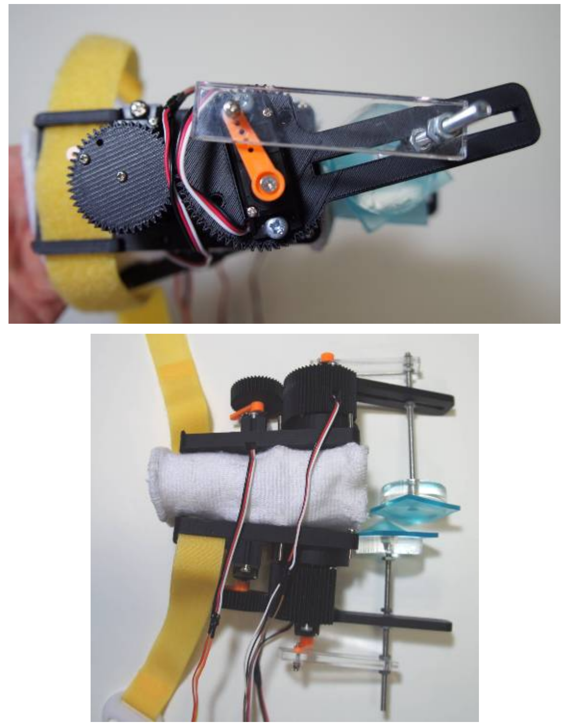

Figure 2: Overview of the device: Top view (upper picture), Side view (lower picture)

The device is composed of four servomotors (Grand Wing Servo-Tech Co.,Ltd, GWSMICRO/ 2BBMG), frames made of ABS (acrylonitrile butadiene styrene), skin stimulator made of acryl, gel sheet made of urethane elastomer, and gears. The gel sheet is placed between the stimulator and the skin to provide sufficient friction. A microcontroller (Arduino Duemilanove328) is used to control the servomotors. Figure 3 shows the appearance and placement of the device on the forearm during use.

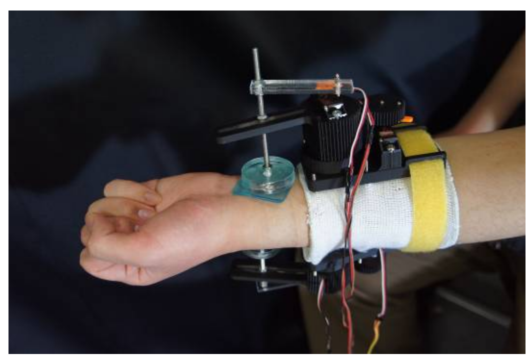

Figure 3: Appearance and placement of the device on the forearm.

3.1 Principle of Operation

Figure 4 shows the configuration of our device, and Figure 5 shows the principle of operation for our device.

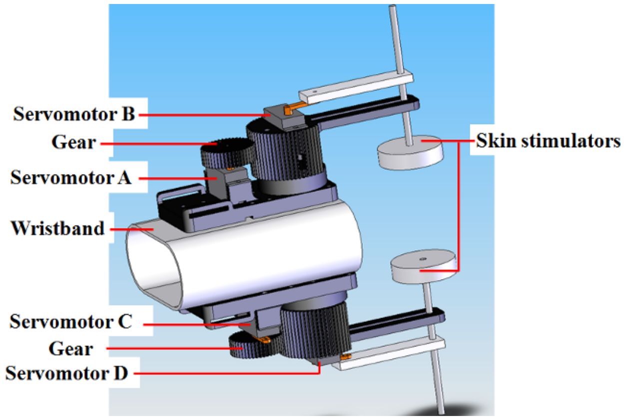

Figure 4 : Device configuration

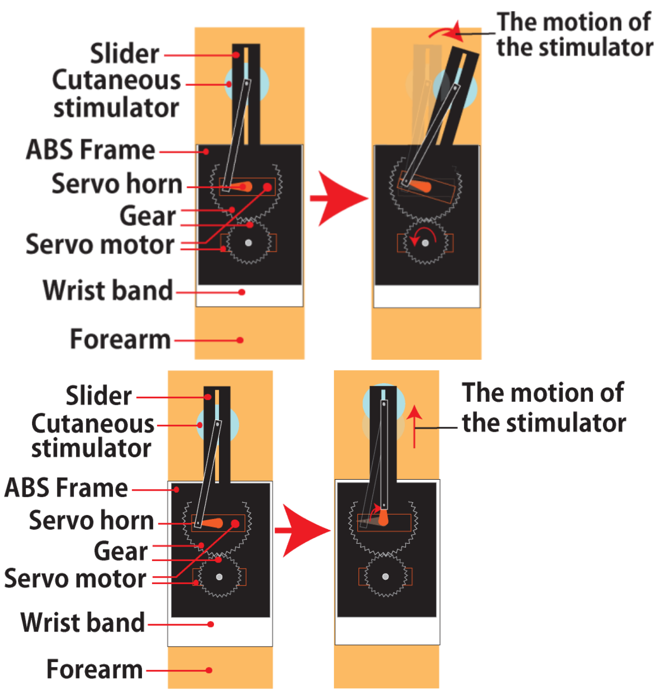

Figure 5: Principle of operation: (Top) Production of left-right deformation, (Bottom) Production of backward-forward deformation

There are two pairs of servomotors, A and C, B and D (Figure 4). Servomotors A and C are attached to the base (back part of forearm) and are responsible for swinging the stimulator to the right and left (Figure 5, top). Servomotors B and D are connected to A and C through the gear, and are responsible for pushing-pulling the stimulator forwards and backwards. A slider-crank mechanism is used to convert the rotation to linear motion (Figure 5, bottom).

The skin deformation is produced by friction between the stimulator and skin. If the skin deformation was continuous, the pulling sensation would be diminished due to sensory adaptation. Therefore, the stimulator produces skin deformation for a second and then returns to the original position for a second. Through this process being repeated, users are able to perceive the pulling sensation continuously.

4. EXPERIMENT

We performed an experiment to evaluate the performance of the haptic device when presenting skin deformation directions.

4.1 Methods & Conditions

Six right-handed participants (four males and two females, aged 21 – 26 yrs) participated in the experiment. The device presented four skin deformation directions (forwards, backwards, right and left) randomly. The participants were asked to answer a question regarding the direction they perceived each skin deformation to be moving. Ten trials were performed per direction transmitted resulting in a total of 40 trials (4×10). During the experiment, the participants were seated and the device was attached to their left forearm with their elbows flexed at 90 degrees (Figure 6). All participants closed their eyes and auditory cues were masked by white noise during the experiment

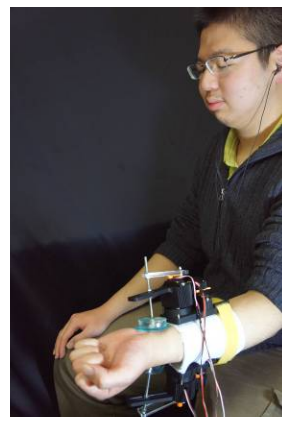

Figure 6: Participant positioning for experiment

4.2 RESULT

Figure 7 shows the average percent correct answer for each of the presented directions. The figure shows that the correct answer rate was greater than 90% in each of the four directions.

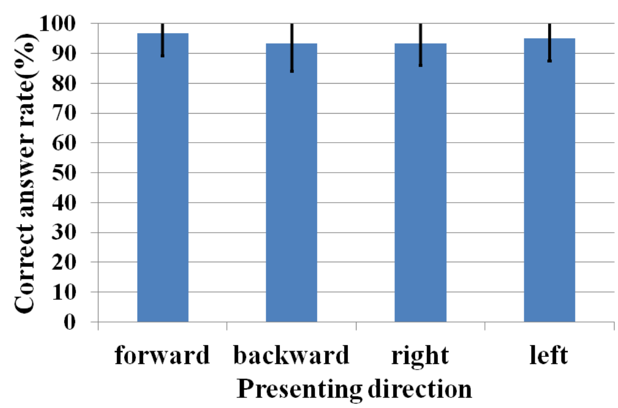

Figure 7: Correct answer rate in each skin deformation direction

5. DISCUSSION

When training hand skills, the trainee's active motion is important. Previously, Lee et al. proposed a method that produced a noise-like haptic disturbance to induce learners' active motion ("pro-active" motion) in a motor learning task [12].

Similarly to our previous report [6], a pseudo-external force was generated by skin deformation in the present study. However, an interesting phenomenon was observed that is related to active motion. Whereas in our previous study all participants reported that they felt as if their arms were "moved" [6], in the present study three out of six participants reported that they "wanted" to move their arms in the direction of the presented skin deformation. This finding implies that although our primary purpose was to produce pseudo external force, there is a possibility that our device can be used to induce pro-active motion.

All the participants reported that the perceived force sensation to the left or right was weaker than the forward or backward sensation. The main reason was the difference in the amount of skin deformation. Because of the shape of the forearm, the skin deformation to left and right (8mm) was less than forward and backward (15mm) deformation. This difference was related to the horizontal motion of the device. It is proposed that users should be able to perceive a stronger force sensation to the left and right by producing skin deformation parallel to the skin surface.

6. CONCLUSION & FUTURE RESEARCH

We have presented a novel haptic device that produces tangential skin deformation to the forearm, and thus, an external force sensation. The experiment showed that our device could present force sensation in the four directions (forwards, backwards, left and right), which are the primary directions required for the practical training scenario when teaching hand skills such as calligraphy. Together with our previous work, we can now produce skin deformation in six directions, which is sufficient for translational movement.

In our future work we will add rotation to the device that will increase the degrees of motion freedom. We will also make the system compact for practical use and continue to use and evaluate the system for haptic training.

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