Development of Wearable Outer-Covering Haptic Display Using Ball Effector for Hand Motion Guidance

Vibol Yem, Mai Otsuki and Hideaki Kuzuoka

Abstract An outer-covering haptic display (OCHD) is a device that imparts a guiding force sensation to the back of a learner's hand and guides the learner to manipulate a tool. Our previous study found that OCHD provides a skin deformation sensation and is able to guide a learner with less drive force than the alternative method where the tool is directly actuated. In this study, we developed a wearable outer-covering haptic display (wOCHD) for hand motion, with two ball effectors to deform the skin and provide a guiding information in four axes of motion.

Keywords Hand motion guidance · wOCHD · Ball effector · Skin deformation

1 Introduction

Laryngoscopy is one of the hand skills that require strength. It is a medical procedure in which a physician or a paramedic manipulates a tool called laryngoscope (Fig. 1, right) to open a patient's mouth to view the vocal folds and glottis.

Haptic systems are one of the major research areas to assist hand skills training to manipulate a tool. The most common method for such systems is to directly operate the tool using an actuator and a learner can directly sense the guiding force from the tool itself [1]. However, our previous study [2] found that this method is not suitable for hand skills training that requires the strong force for manipulation (i.e., when a learner needs to hold the laryngoscope tightly), because the guiding

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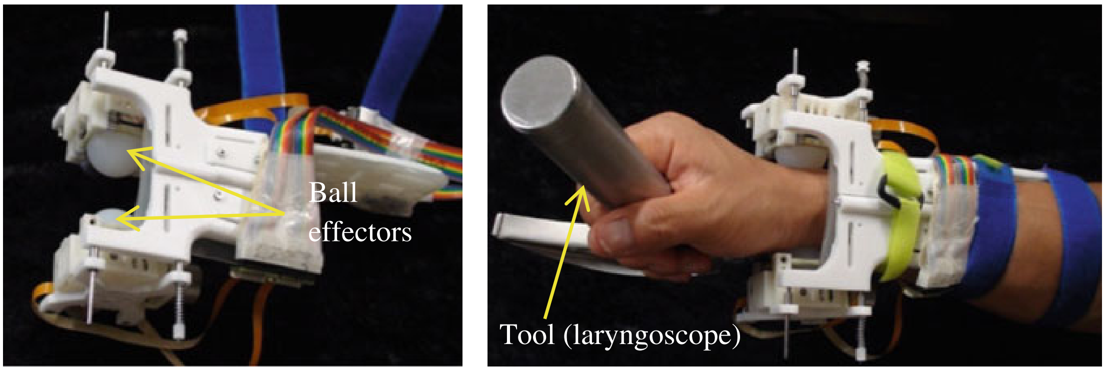

Fig. 1 wOCHD (*left*) and wOCHD worn on right hand (*right*)

forces inevitably become large, and this method typically requires a greater size and cost of the system.

Moreover, it is not an effective method for hand skills training because it is a passive learning technique, in which mainly the actuator manipulates the tool and the learner only follows its motion [3]. Although Saga et al. [4] proposed active learning method, in which learner tries to cancel the force produced by haptic device, in the case of laryngoscopy, it also requires a greater size and cost of the system.

To solve these issues, we proposed an outer-covering haptic display (OCHD), which imparts a guiding force to the back of a learner's hand by deforming the learner's skin [2]. Our previous studies showed that an OCHD is able to present learners in pitch rotation with less drive force than that is required for an actuator [2], and it is an effective method for hand skill learning [3].

The aim of this study was to develop a wearable OCHD (wOCHD) that uses ball effector to deform hand's skin. In this study, we used two ball effectors to provide guiding sensation in four axes of motion. Because wOCHD is a portable device, it does not require ground-based actuator to present guiding force to the learner's hand.

Regarding the wearable haptic device, Nakamura et al. introduced Hanger reflex device for presenting the pseudo-force sensation by skin deformation on wrist. The pseudo-force sensation makes user rotates his/her wrist in one axis [5]. On the other hand, we aimed to provide a guiding sensation in multiple axes of motion.

2 Wearable Outer-Covering Haptic Display

Kuniyasu et al. [6] proposed a wearable device that uses two plate effectors to deform the skin of the forearm and found that skin deformation can be used for training hand skills. Rotational skin stretch was also found to be effective for motion training of joint or limb [7]. In this research, we focused on applying skin deformation on the user's wrist using ball effectors (Fig. 1). The advantage of this method is that it can continuously deform the skin, even when slip occurs between the effectors and the skin.

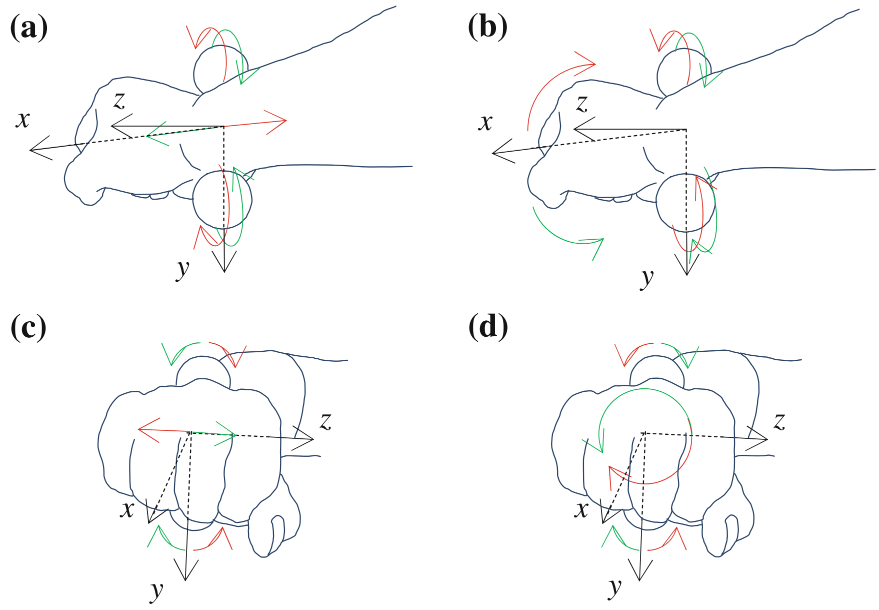

Fig. 2 Concept sketch of guidance in four axes (*x*, *yaw*, *z*, and *roll*). **a** Guiding in *x* axis. **b** Guiding in *yaw* rotation. **c** Guiding in *z* axis. **d** Guiding in *roll* rotation

Figure 2 shows how wOCHD controls two ball effectors to provide a guiding sensation in four axes of motion (*x*, *yaw*, *z*, and *roll*). As shown in Fig. 3, the actuator controls the ball effector in two degrees of freedom by using four shafts. Each pair of opposing shafts is moved by a single motor. Each ball was made from silicone and its diameter is 30 mm. Rotation angle of the ball was measured by hall sensors embedded in the motors. If there is no slippage between the ball and skin, the amount of skin deformation is equal to the amount of the rotation of the ball.

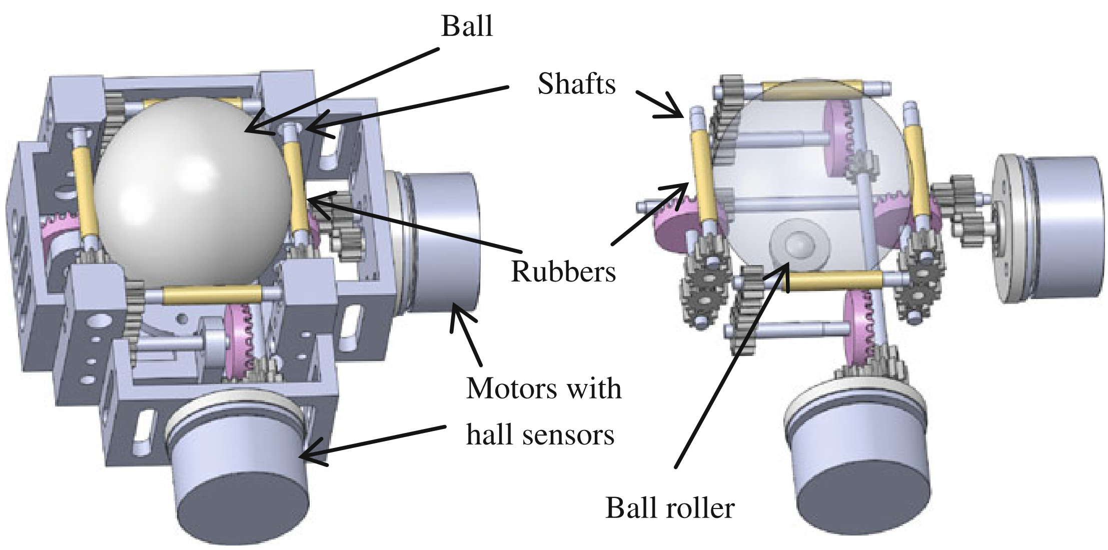

Fig. 3 Actuator (*left*) and four shafts' mechanism to actuate the ball (*right*)

3 Pilot Test and Discussion

For initial stage of our study, we conducted a pilot test to confirm that our wOCHD is able to provide a guiding sensation in four axes of motion. Four subjects participated in this test. Each subject was presented with skin deformation sensation in one of the eight random directions (positive and negative motion in each of the four axes). We assumed that there was no slippage occurred and the amount of skin deformation was about 10 mm. Each direction was presented three times, so that there were 24 trials in total for each subject.

The correct answer rates were 100 % for the *x* axis and 96 % for *yaw* rotation, but only 62 % for *roll* rotation and 60 % for *z* axis. The correct answer rate for *z* axis was low because they were confused with *roll* rotation, and vice versa. The subjects commented that the skin deformation strength of the two balls were not equivalent, which made it difficult to distinguish between the *x* axis and *yaw* rotation, and the *z* axis and *roll* rotation. We thought that this phenomenon occurred because of the different intensity of the sensation that depends on the location of the skin or the unequivalent pressure of the two balls. According to this result, in order to help subjects to perceive the guiding direction correctly, we need to add a force sensor to measure skin deformation more accurate even though the slippage occurred and a calibration to adjust the intensity of skin deformation sensation of the two balls.

4 Conclusion and Future Work

We developed wOCHD using two ball effectors to provide the skin deformation sensation to a user's wrist. The wOCHD is capable of guiding a hand in four axes of motion.

In our future work, we will improve our system by changing the effector's material to provide the equivalent pressure and reduce the slippage. We will investigate the relationship between the amount of deformation of the skin and the hand motion induced by the deformation. Based on the result, we will develop an

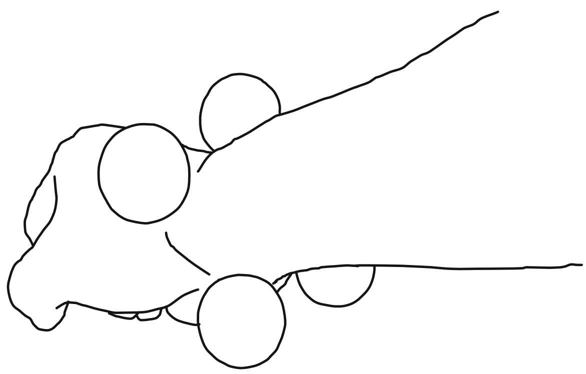

Fig. 4 wOCHD with six axes of motion using four ball effectors

algorithm for hand motion control. Additionally, in order to provide guidance with six axes of motion, we will develop wOCHD that has four ball effectors where additional two balls are for *y* axis and *pitch* rotation (Fig. 4).

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