Buttock Skin Stretch Devices for Enhancing Driving Experience

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ABSTRACT

A new concept of buttock skin stretch to induce the perception of shear forces while sitting is reported. The buttock skin stretch is suitable for a driving simulator to enhance the whole-body experiences such as the centrifugal force of the car and the inclination of the car body in driving.

1 INTRODUCTION

Skin stretch is a potential approach to deliver kinesthetic information by cutaneous stimuli with a compact device. It is known that tangential displacement on the surface of the skin induces the perception of force, including directions. Different types of skin stretch devices have been proposed for the finger pad [1–4], palm [5], and the upper limb [6, 7]. The skin stretch has a great advantage to realize a compact and portable mechanism because large actuators are not necessary just for producing lateral skin deformations.

We introduced the idea of skin stretch to the buttock skin to induce the shear-force-like feeling while sitting. We have developed a single-DoF buttock stretch device [8] and a two-DoF device [9], which deforms buttock skin in the frontal and sagittal axes. The perceived shear force induces not only local force sensation but whole-body experiences in a seat. We confirmed that shear forces corresponding to the acceleration of optical flow induce acceleration sensation of self-motion in a riding platform [8]. The shear force could also induce surmounting feeling on terrains such as a bump and hole.

The buttock skin stretch device can be applied for a driving simulator to enhance whole-body experiences. We demonstrated that the device could represent acceleration/deceleration, centrifugal force at the time of curving, and inclination of the roll and pitch angles of the car body in a driving simulator with a steering wheel [9].

This paper reports an overview of our previous works and proposes an application for driving simulators.

2 Buttock Skin Stretch Devices

We developed a single-DoF buttock stretch device [8] and a two-DoF device [9]. This section describes the overview of our devices.

2.1 Single-DoF Device

We developed a tactile device to present buttock skin stretches. Fig. 1 shows an image of the developed device [8]. Two contactors are placed on the left and right of the top to make contact with each buttock. The two contactors move to the left and right while the outer circumference of the contactors holds the outer buttocks. The top of the contactor and the contacting base were covered with a rubber sponge to fit the buttock shape and prevent slippage. This configuration makes the buttock skin deform efficiently without movement of the upper body. Driving actuators only require the power to deform the buttock skin. Each contactor was mounted on a belt conveyor, and a servo motor controlled the lateral displacement. The device does not require large displacement because small deformation is enough to stretch the skin surface. The required range to induce force-like feeling was less than ± 10 mm. This small movement is another advantage of the skin stretch approach.

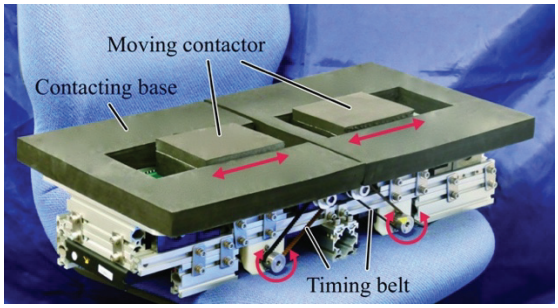


Fig. 1 Single-DoF buttock skin stretch device [8].

2.2 Two-DoF Device

We also developed a two-DoF buttock skin stretch device which realizes skin deformation in the lateral and frontal axes on each buttock. Fig. 2 shows the image of the device developed. The two contactors deform the skin by sliding horizontally as same as the single-DoF device.

A parallel linear drive mechanism was introduced to realize two degrees of freedom within a limited thickness of the device, as shown in Fig. 3. Two feed screws are installed in a parallel and move the two sliders respectively by rotating screw with a stepping motor. Each slider mounts a linear guide which inclines by 45 degrees against the feed screw. The contactor base is connected with two the linear guides in an orthogonal

direction. As shown in Fig. 3 (a) and (b), when the sliders move to the same directions with keeping the same distance between the sliders, the contactor base moves to the left and right. As shown in Fig. 3 (c) and (d), when the sliders move to different directions, the contactor base moves forward and backward by sliding on the linear guides, where the direction is depending on the distance between the sliders.

The proposed configuration has advantages for 1) controlling the sliders because the weights on the screws are even and 2) a flat structure to reduce the thickness of the device. The available range of movement in each direction is 40 mm, which is sufficient to handle skin deformation on buttocks. The maximum speed of the contactor is 16 mm/s, which depends on the available speed of the stepping motor.

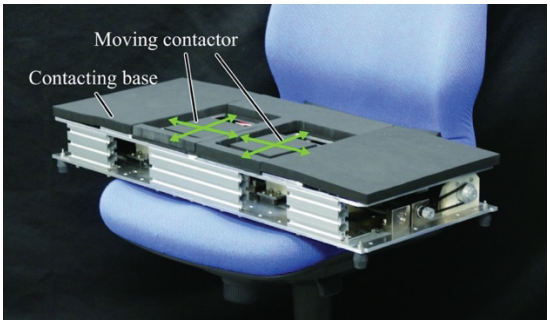


Fig. 2 Two-DoF buttock skin stretch device [9].

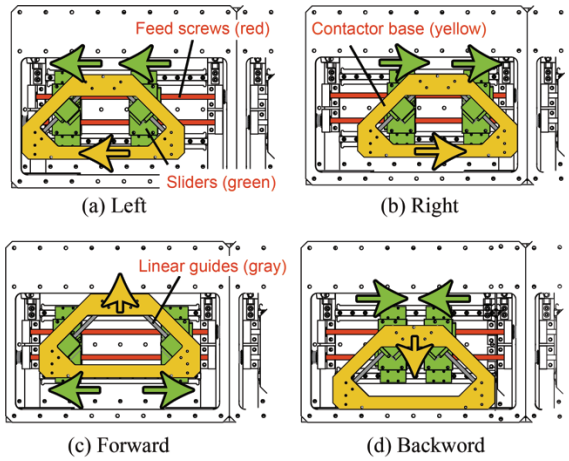


Fig. 3 Drive mechanism of Two-DoF device.

3 Perceptual Effects

3.1 Perceived Shear Force

Skin stretches can induce kinesthetic sensation such as a force toward the deformed direction as reported conventional approaches [1-4]. We also investigated the relationships between the perceived shear force and the lateral displacement of contactor on the buttock skin [8].

In the experiment, the perceived share force was evaluated with the magnitude estimation method against five types of stimuli that have different maximum displacement (d=3.0, 4.5, 6.0, 7.5, and 9.0 mm) as shown in Fig. 4 (a). The estimated magnitudes of the shear force are shown in Fig. 4(b) and (c), which corresponds to the left and right directions, respectively.

The results showed that the perceived shear force increased almost linearly corresponding to the skin stretch displacement, where the fitted model's power exponents were almost 1.0 in either direction (Left: 1.08, Right: 1.03). The similar linearity is reported in the related studies on the finger pad skin stretch [1]. These results show that the proposed buttock skin stretch device has good reproducibility of the induced forces. Recently, we also confirmed the similar linearity in the forward and backward directions, while the determined parameters were slightly different due to the asymmetric shape of the body in the sagittal plane. The details will be reported in a future publication.

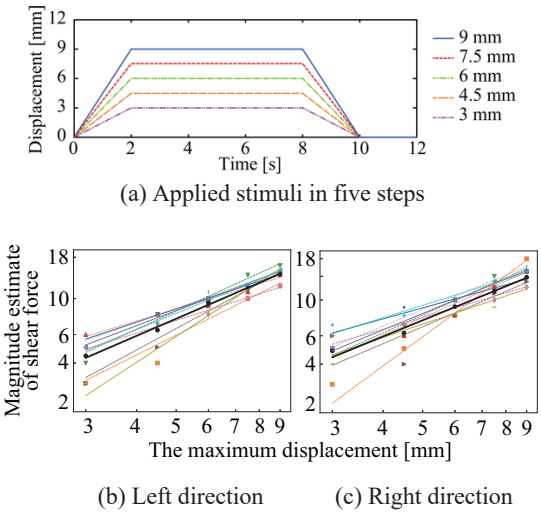


Fig. 4 Magnitudes of the perceived shear force.

3.2 Acceleration Illusion of the Whole Body

One of the features of the buttock skin stretch approach is that the buttock skin stretch is suitable for inducing whole-body experiences in sitting situations. Figure 5 illustrates the concept of the whole-body acceleration illusions with buttock skin stretches. It is known that visually presented optical flows induce the sense of self-motion as a whole-body experience. Buttock skin stretches could enhance the whole-body experience associating with visual motion effects.

We investigated the possibility of bias in acceleration sensation by buttock skin stretch as a pilot study [8]. We experimented to determine whether buttock skin stretch creates a bias the illusion of self-motion acceleration by the visual stimulus called a vection.

The test stimulus is a combination of visual and haptic stimuli. Visual stimuli were five types of optical flow with maximum acceleration (a=0.06,0.09,0.12,0.15, and 0.18

[m/s^2]). The haptic stimuli were also selected from the five types of buttock skin stretches with different maximum displacement (d=3,4.5,6,7.5, and 9 [mm]), as shown in Fig. 6 (a), which are similar to the acceleration profile of optical flows. In each trial, the modulus stimulus was presented for 20 seconds followed by a test stimulus for 20 seconds. After receiving two stimuli, the participants answered questions on the subjective magnitude of the maximum acceleration toward the moving direction of the test stimulus. They were instructed that the magnitude of the modulus is 10.

Fig.6 (b) and (c) shows the relationship between the maximum acceleration of optical flow and the geometric mean of the estimated magnitudes of self-motion acceleration. The perceived acceleration tended to increase according to the increasing acceleration of the visual stimulus in all 12 conditions. This tendency suggests that the participants perceived the illusion of self-motion acceleration even though buttock skin stretch was added to the visual stimulus.When the acceleration of the visual stimulus is small, the variation of estimated magnitudes between the conditions tends to be large.

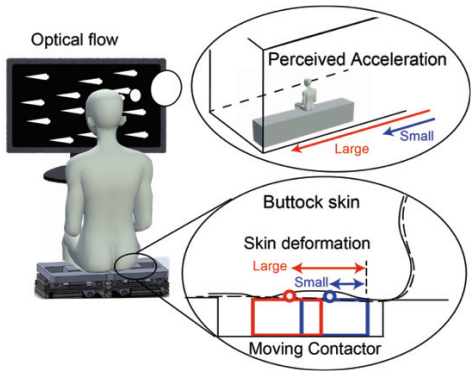
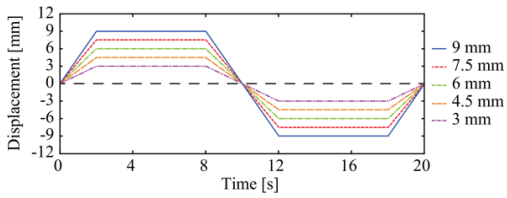
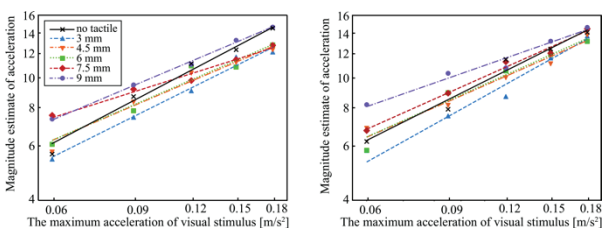


Fig. 5 Concept of the whole-body acceleration illusions with buttock skin stretches



(a) Applied buttock skin stretches in five steps



(b) Left direction (c) Right direction

Fig. 6 Magnitude estimates of the perceived acceleration biased by buttock skin stretches.

3.3 Perceived Shape of Terrain

Buttock skin stretch can also induce the whole-body experience of inclination of the ground shapes when a sitting virtual object surmounts the terrain. This phenomenon is reasonable because our buttock skin could deform in response to the acceleration of the riding vehicle and the gravity direction on slopes. We have confirmed that both driving forces; accelerations and the gravity changed by terrain could induce the self-motion illusion of surmounting terrains, including convex and concave shapes. We investigated the influence on the perceived shape by applying visual when the acceleration changes when riding on small convex/concave shapes, as shown in Fig. 7. We confirmed that the skin stimulus sometimes had larger effects than visual stimulus in a small terrain shape perception. The details will be reported in a future publication.

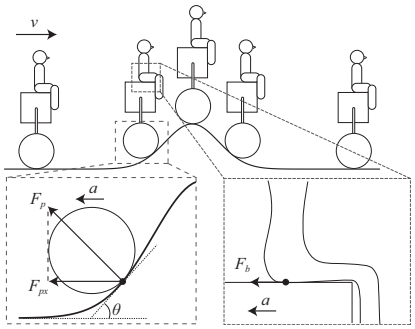


Fig. 7 Concept of the terrain shape perception induced by buttock skin stretch in response to acceleration changes.

4 Application for Driving Simulators

Buttock skin stretch approach is suitable for enhancing the whole-body experience in a driving simulator. Conventionally, a motion platform to make the body get physically inclined and accelerated is needed to reproduce realistic driving experiences. However, motion platforms require large actuators and structures to drive a whole seat and driver's body. In contrast, the buttock skin stretch device just requires small actuation of skin and does not require to drive the whole weight of the body. Thus, stimulator could be installed in a seat. Buttock skin stretches can represent acceleration/deceleration, centrifugal force at the time of curving, and inclination of the roll and pitch angles of the car during a drive as illustrated in Fig. 8.

We demonstrated a driving experience enhanced with the two-DoF buttock stretch device [9]. The demonstration setup is shown in Fig. 9. We just need a chair to put the skin stretch device. The driving simulator was built with the Unity (Unity Technologies) as shown in Fig. 10. We simulated the acceleration of the car in the

horizontal plane. We also reflected the gravity due to the inclination change on terrains. These forces are integrated and represented as 2-DoF horizontal movements of the contactor on the buttocks. The driving simulator was demonstrated in AsiaHaptics 2018 in Korea and other domestic conferences in Japan. Many participants were satisfied with the driving experience and had positive opinions.

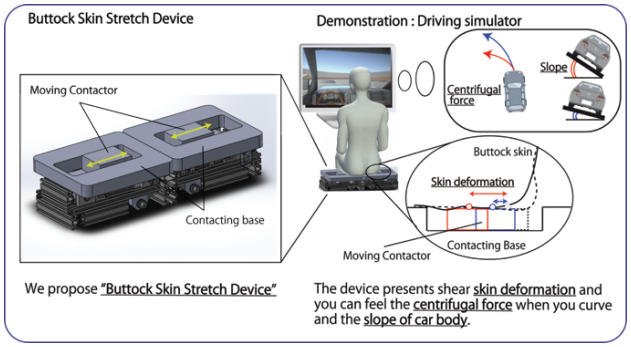


Fig. 8 Concept of buttock skin stretch for driving simulators

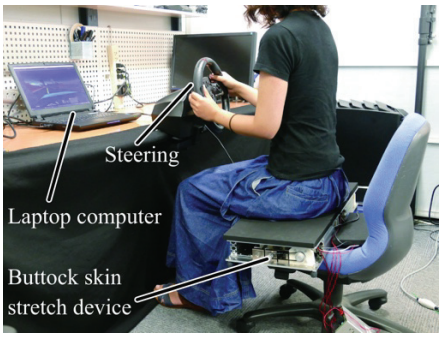


Fig. 9 Demonstration setup for driving simulators.

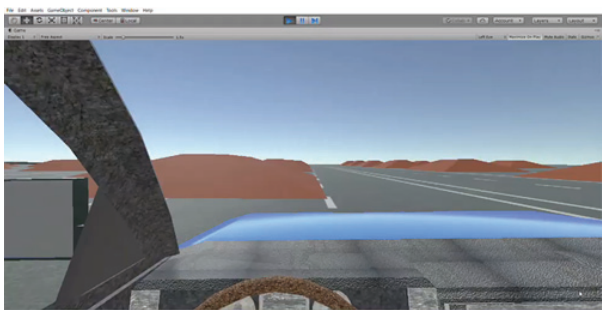


Fig. 10 Example of image of driving simulator.

5 CONCLUSIONS

A new concept of buttock skin stretches to induce the perception of shear forces while sitting is reported. This paper introduced the overview of our previous works and proposed an application for driving simulators.

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