Haptic Bed: Bed-style Haptic Display for Providing Weight Sensation

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ABSTRACT

We developed a bed-style haptic display "Haptic Bed" that provides weight sensation to wide area of the user's body. This system comprises motors, belts, a cushion and a comforter to press and swing the user lying on the bed. Haptic Bed is a type of whole-body haptic interface, characterized by the presentation of low-frequency force with multiple degrees of freedom. The prototype system with two motors can present a weight sensation to approximately five regions of the abdomen. Although a sensation is only presented to the abdomen in this study, Haptic Bed can present a weight sensation to a wider area by increasing the number of motors. The system has the potential to enrich the audio visual experience in several ways, such as by expressing the sensation of a horrific ghost sitting on the user as part of entertainment content, or by presenting the existence of a remote relative as a telecommunication tool. Overall, the system changes a bed into a new medium through which immersive contents are presented in an immersive manner.

Author Keywords

Haptic bed; haptic display; weight sensation; virtual reality

ACM Classification Keywords

H5.2 [Information interfaces and presentation]: User Interfaces - Haptic I/O.

INTRODUCTION

Haptic displays for the whole body have been developed to enrich the content of audiovisual entertainment such as when listening to music, watching movies and playing video games. For example, chair-type vibrotactile displays provide vibration from the backrest to enrich music and video game experiences [3, 5]. Lemmens et al. proposed a jacket-type vibrotactile display with 64 vibration motors to add tactile feedback to audiovisual content [6].

These studies provide vibration (i.e., medium-to-high frequency component of the perceivable tactile frequency range) to a wide area of the user's body. While sound and impact can be expressed or enhanced by the vibration, it is difficult to present a low-frequency component such as pressure, which is an indispensable component in expressing interaction with other entities, such as remote friends or virtual characters.

We focused on the bed as a medium for presenting a force sensation and feeling of weight sensation to the whole body; we call our system the Haptic Bed (Figure 1). We spend a third of our lives in bed, which is a place not only for sleeping but also for reading, watching movies and playing video games. Additionally, a bed is a good candidate for presenting force and vibrotactile sensations because the body is wrapped in a comforter and relatively large devices can be embedded under the bed.

Figure 1. Conceptual image of Haptic Bed

RELATED WORK

There have been numerous attempts to use the bed as a place for entertainment. A bed has been used as a remote communication medium by transmitting the sound of breathing [2]. A pillow-mounted pneumatic actuator has also been used for remote communication [4]. There have

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also been several interactive artworks that share the space on the bed visually, by camcorder and projector [11] or head-mounted display [9]. Some of these studies combined vibration with visual and auditory effects, but as far as the authors know, there have been no attempts to present a weight sensation to the human body.

Numerous haptic displays that present a force sensation have been developed; e.g., Falcon [10], PHANToM [7] and SPIDAR [1]. They express a force sensation by exerting a real physical force. In contrast, some works have provided a force sensation through skin deformation; e.g., Gravity Grabber [8]. Gravity Grabber is a device that provides weight sensation through shear deformation and normal deformation of the finger skin by winding a belt with two motors.

Many of these devices have presented force sensations to the fingertips or hand. In contrast, some devices have presented force sensations to the body more generally via wearable devices; e.g., Huggy pajamas [14] and Sense-Roid [13], which both used pneumatic actuators. However, to adopt their methodology to our purpose, there are three issues to address. The first issue is that these wearable devices need to be able to be worn, which requires certain amount of time, which is an important practical issue. The second issue is that the response time is not fast enough for synchronization with sound and video contents owing to the limitations of pneumatic actuators. The third issue is that the force direction is limited to normal pressure, which is adequate to express a hug or squeeze but not suitable for other situations such as moving or caressing.

Our work addressed these three issues using multiple motors under the bed and a belt-type actuation. By limiting the situation to a bed, we can employ large actuators, which are placed under the bed (i.e., we do not need to "wear" devices). Tele-sofa [12] applied a similar mechanism to a sofa to provide the sensation of sitting near a person. Haptic Bed can readily co-exist with an existing vibrotactile actuation system.

SYSTEM

System Structure

Haptic bed comprises a bed, two gear-head motors (Maxon Motor, reduction ratio of 19:1, RE 25, 10 W), a bobbin, a rope, a belt, a cushion, two motor drivers (Toshiba, TA8429HQ), and a micro-controller (NXP, mbed NXP LPC1768) (Figure 2). Weight sensation is presented by winding the rope with the two motors. The user's body is sandwiched by the bed and the comforter. The cushion is used to provide more pressure than is possible with only the comforter.

Weight sensation and position

One sensation to present with Haptic Bed is the sensation of weight. As shown in Figure 3, weight is presented by winding the rope with the two motors and pressuring the body with the cushion and comforter. It is possible to change the weight by changing the winding force. Furthermore, the position of the weight can be altered by changing the ratio of the two motors. Additionally, Haptic Bed can present an intermissive weight sensation by actuating the motors periodically.

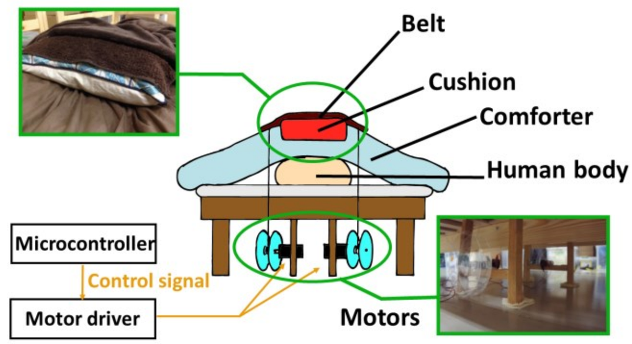


Figure 2. System structure

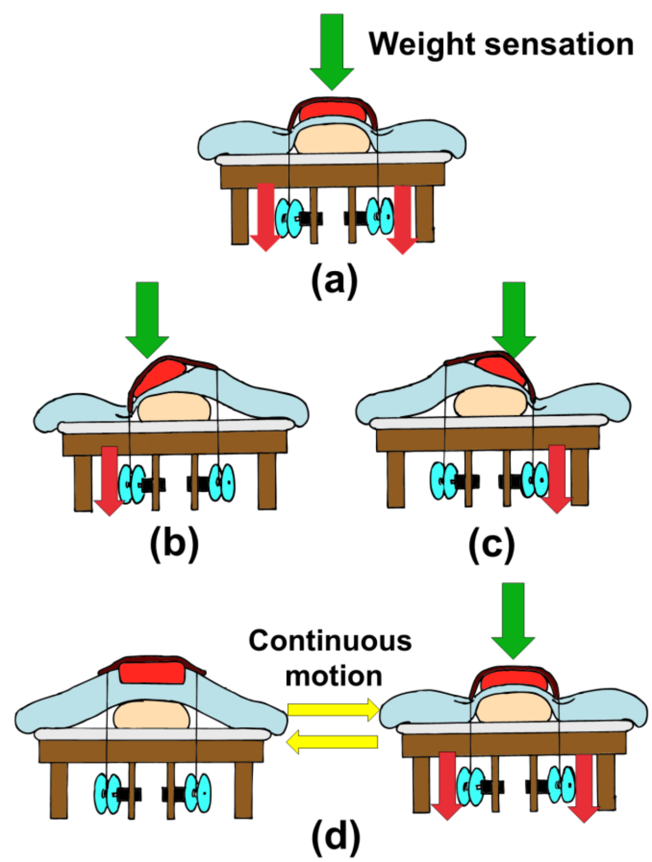


Figure 3. Device motion; (a) Weight sensation to the center, (b) weight sensation to the left, (c) weight sensation to the right, (d) intermissive weight sensation

Shear-force sensation

Haptic Bed can also present the sensation of a shear force. As shown in Figure 4, the comforter is shifted left or right by operating the two motors in different directions, because the belt is fixed to the comforter.

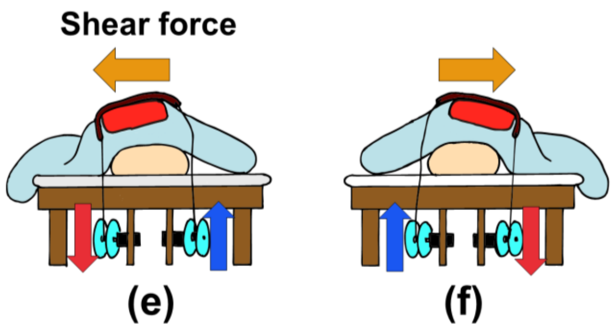


Figure 4. Device motion; (a) shear-force sensation in the left direction, (b) shear-force sensation in the right direction.

EXPERIMENT

We conducted an experiment to verify if Haptic Bed can present weight sensations to different areas of the user's body by changing the ratio of the two motors.

Experimental conditions

Five conditions were prepared as listed in Table 1. The motors were controlled by pulse-width modulation (PWM).

Condition	PWM Ratio of the left motor [%]	PWM Ratio of the right motor [%]	Ratio (right)/(right +left)
Condition 1	100	0	0.0
Condition 2	100	50	0.33
Condition 3	100	100	0.50
Condition 4	50	100	0.67
Condition 5	0	100	1.0

Table 1. Experimental conditions.

Experimental procedure

We recruited six participants (six males, 21–23 years old). The participants lied on their backs on Haptic Bed putting out their arms (Figure 5). They wore active noise-canceling headphones (Bose, QuietComfort15) and listened to white noise at a pleasant volume to avoid sound cues. The center position of the cushion was set just above the navel of the participant. Scale marks were placed on the comforter. The zero position of the scale was set at the left end of the participant's abdomen. To avoid visual estimation, participants were instructed to look at the ceiling or close their eyes.

One trial consisted of 2 seconds of presentation of the stimulation. The participants indicated the position of maximum weight sensation by pointing to a scale with their fingers. Each condition was presented 10 times, with the 50 trials in total being presented in random order.

Figure 5. Overview of the experiment.

RESULT

Figure 6 shows the experimental results for each participant. The vertical axis represents the average position of maximum weight sensation, which was normalized; a value of zero corresponds to the left-most part of abdomen and a value of 1 corresponds to the right-most part. The horizontal axis represents the conditions. The error bars indicate the standard deviation.

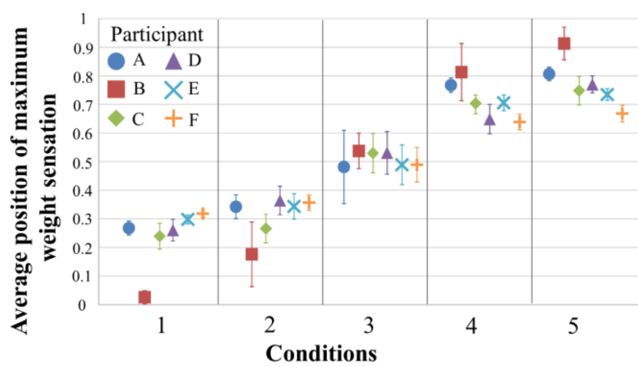


Figure 6 Average positions of maximum weight sensations for the five conditions

DISCUSSION

The results show that users could differentiate all five positions (i.e., the overlaps of standard deviations among conditions were small). The indicated position for condition 3 had larger deviation than the indicated positions for the other conditions. This is possibly because of the size of the cushion. As illustrated in Figure 3, the pressure distribution change with the orientation of the cushion, and participants might have felt a wider area of pressure under condition 3 than under other conditions. Free comments made by participants after the experiment, such as "I felt the weight sensation over a wide area, so I found it difficult to answer" and “There were moments that I felt the weight sensation in two areas”, support this hypothesis.

Additionally, some participants commented that when the force was concentrated on a small area (conditions 1, 2, 4, and 5), they felt as if they were being mounted by another person.

APPLICATION

We show here two examples of using Haptic Bed to enrich the virtual-reality experience. We used Haptic Bed, a head-mounted display (Oculus Rift, http://oculusvr.com) and a Unity3D engine (http://unity3d.com). In one scenario, a virtual character lies on the user’s body, and the user can feel the weight of the character (Figure 7 [a]). In the other scenario, a flying monster attacks the user, and the user can feel a collision with the monster (Figure 7 [b]).

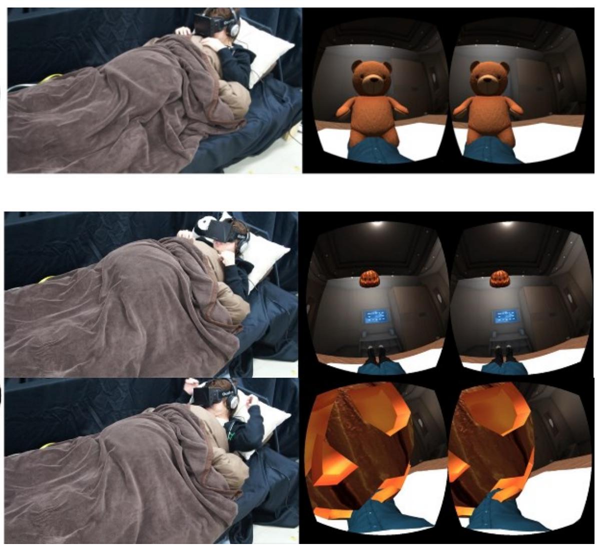
(a)
(b)


Figure 7. Device motion; (a) A virtual character lies on the user’s body, (b) a monster attacks the user.

CONCLUSION

In this paper, we developed a device to present a weight sensation to the whole body for an in-bed situation. The device named Haptic Bed pulls the user’s body with two motors, and can change the position of the force by changing the force ratio of the two motors. We conducted an experiment to verify the ability of Haptic Bed to present a sensation to different positions, and confirmed that Haptic Bed has the ability to present a sensation to at least five points on the abdomen. Our future work includes adding more motors to present a sensation to the other parts of the body, improving the resolution, and combining Haptic Bed with entertainment content such as that of video games.

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