HapBelt: Haptic Display for Presenting Vibrotactile and Force Sense Using Belt-winding Mechanism*

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Figure 1: Our belt-driven method enables vibration and force feedback in the game for smartphone, walking navigation by presenting a rotational force to the wrist, and being hit sensation in VR fighting game by presenting and force sense (left). Smartphone, wrist, and head-type device(right).

ABSTRACT

We developed a haptic display that drives the skin via a lightweight belt with a DC motor. AC signals to the two DC motors generated vibration of the belt, and the vibration is directly presented to the skin in contact with the belt, while DC signals to the motors wind up the belt, and force sense is presented by causing skin deformation. By combining these two driving modes, high-fidelity vibration and directional force sensation can be presented simultaneously, with compact and low energy setups, which can be extended to various parts of the body.[1]

CCS CONCEPTS

•**Human-centered computing → Haptic devices;**

KEYWORDS

Belt Winding; Haptic Display; Human Manipulation; Navigation; Pseudo-Force

ACM Reference format:

Takuto Nakamura, Vibol Yem and Hiroyuki Kajimoto. 2017. HapBelt: Haptic display for presenting vibrotactile and force sense using belt winding mechanism. In Proceedings of SIGGRAPH Asia Emerging Technologies, Bangkok, Thailand, November 2017 (SIGGRAPH Asia '17 Emerging Technologies), 2 pages.
DOI: 10.1145/3132818.3132825

1 INTRODUCTION

Virtual Reality (VR) experience now became quite popular, mainly due to commercialization of inexpensive high-performance head mounted displays (HMD), The VR experience incorporates visual, auditory, and haptic feedback, among which the haptic feedback is relatively immature. The haptic feedback is a combination of vibration sense, static skin deformation (including lateral skin stretch), force sense, and temperature sense. The temperature sense has relatively low priority, and the static skin deformation sense and force sense are inseparable and numerous work tried to express force sense by skin deformation [Minamizawa et al. 2007]. However, it is still difficult to present both vibration and skin deformation in various parts of the body.

For vibration feedback, an eccentric motor was frequently used, which is difficult to independently control vibration frequency and amplitude. Linear Resonant Actuator (LRA) was adopted in numerous recent applications, but it has limited frequency range. A voice coil type vibrator can be driven at a relatively wide frequency, but its energy efficiency is poor since it does not utilize resonance, and it has problems such as heat generation. Regarding force feedback, since it is necessary to reproduce the physical force, the device becomes expensive and large, which hinders popularization.

Many wearable devices for fingertips have been proposed [Pacchierotti et al. 2017], but issues requiring complicated mechanisms still remain and there is no extensibility to present to various parts of the body. For presentation with compact device, methods using asymmetric acceleration vibration [Amemiya et al. 2014], and muscle electrical stimulation [Lopes et al. 2017] have

SA '17 Emerging Technologies, November 27-30, 2017, Bangkok, Thailand
ACM 978-1-4503-5404-2/17/11.
10.1145/3132818.3132825

been proposed, but each of them has certain limitation such as unnecessary vibration feeling and safety against long-term use.

As a method for simultaneously presenting vibration and force sense, a method using air balloons has been proposed [Kon et al. 2017]. For force sense presentation, they used illusory force phenomenon called hanger reflex, which is caused by compression by air balloon, and vibration sense is also presented by putting in and out the air. However, this method has a problem that the time responsiveness is poor because of the pneumatic actuator.

To implement a haptic display that satisfies (1) compactness that does not disturb physical exercise, (2) low energy consumption suitable for wearable applications, (3) high fidelity vibration and pressure sense including lateral skin stretch for high quality sense presentation, and (4) scalability to apply to various places, we propose a vibration and force sense presentation method by a belt winding mechanism using two DC motors. This method consists of two DC motors and a belt that directly contacts skin. Compared with the Gravity Grabber [Minamizawa et al. 2007], which has similar configuration to the fingertip, this method extends it to be used both as a force and vibration display, by using our previous finding that DC motor can be used as a vibrator with wide frequency range [Yem et al. 2016]. Due to the simplicity of the mechanism, this method can be applied to multiple parts of the body.

In this paper, we show the details of the device using this method and the application examples to smartphone, wrist, and head (Figure1).

2 HAPBELT

In this method, the user directly touches the belt driven by the DC motor to present the tactile sense. The tactile sense presentation part of the device is composed of two DC motors and film belts. A DC motor is mounted on a mounting case. In this paper, we prepared a motor mounter for tactile presentation to smartphone, wrist and head (Figure1 right). This device is driven by a system composed of a PC, a microcontroller (mbed LPC1768, NXP Inc.), a DA converter (LTC1660CN, Linear Technology), an operational amplifier (OPA2544, Burr-Brown Corporation), and two DC motors (HSV1S, S.T.L. JAPAN). The microcomputer outputs a waveform according to the control signal from the PC, and the DC motors are driven via the DA converter and the operational amplifier.

Our system can present vibrations in a wide frequency range, and force sense in body rotation direction and compression direction. The respective drive patterns are shown below.

The vibration presentation of this method is performed by vibrating the belt with a DC motor driven in phase. While conventional vibrator needs to vibrate the whole housing itself, our method directly vibrates the belt contacting the skin, which leads to much higher energy efficiency [Nakamura et al. 2017]. We have confirmed that comparing with a typical transducer (Haptuator Mk2, Tactile Labs), the energy needed to present the same subjective intensity became 5% at 25 Hz, 9% at 50 Hz, 55% at 100 Hz, 26% at 200 Hz and 85% at 400 Hz.

It is known that pressure or shear deformation to the skin can be felt as external forces [Minamizawa et al. 2007]. We applied this skin deformation method to various parts of the body. It presents vertical drag and shear deformation by driving two motors in phase and in reverse phase respectively. As our method can be applied to a large area of the body, we can express not only a translational force, but also a torque feeling by twisting the whole skin of arm, head, ankle, and various other locations.

As described above, the vibration is generated by the AC signal applied to DC motors, and the force sense is generated by the DC signal of the same or reverse phase applied to DC motors. Therefore, it is easy to combine the two signals to present vibration and force sense at the same time.

3 DEMO EXPERIENCES

The main feature of our method is scalability that can be worn throughout the body. As a reasonable part for mounting the device, we show the demonstration in the situation where this method is worn on the smartphone, wrist and head.

We give haptic feedback to the game of smartphone and improve the experience. (Figure1 left). In the game using the sling shot, the reaction force generated when the rubber is towed, and the vibration when the rubber is opened are presented. After firing, the target of tactile feedback is changed to the thrown object, and the impact when colliding with obstacles is expressed by vibration and force sense. By mounting the device on the arm, we apply our method to walking navigation (Figure1 left). Our method presents walking direction by twisting the arm, which requires lower mental load. By mounting the device on the head, we present tactile feedback to the head in the VR space (Figure1 left). Especially in fighting games, it presents vibrations and force sensations when the users are hit by enemy players. As our method can present torque feeling, as well as transitional force and vibration, we can separately express "straight" and "hook". Our high-fidelity vibration presentation can also achieve low-latency shock sensation.

Acknowledgments

This research is supported by JSPS KAKENHI Grant Numbers JP16J09326 and by the JST-ACCEL Embodied Media Project.

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