HapCube: A Tactile Actuator Providing Tangential and Normal Pseudo-Force Feedback on a Fingertip

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ABSTRACT

We developed a tactile actuator named HapCube that provides tangential and normal pseudo-force feedback on user's fingertip. The tangential feedback is generated by synthesizing two orthogonal asymmetric vibrations, and it simulates frictional force in any desired tangential directions. The normal feedback simulates tactile sensations when pressing various types of button. In addition, by combining the two feedbacks, it can produce frictional force and surface texture simultaneously.

CCS CONCEPTS

•**Hardware → Sensors and actuators; Haptic devices;**

KEYWORDS

Haptics, asymmetric vibration, compliance

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1 HAPCUBE DESIGN

HapCube [Kim et al. 2018] consists of three orthogonal voice coil actuators (three electromagnets and five neodymium magnets) (Figure 1 (a)). The five magnets are arranged with the same poles facing inward to make the inside magnetic field symmetric in order for the electromagnets to move independently. Two voice coil actuators on a tangential plane are aligned orthogonally and connected with a plate by titanium rods (paramagnetic). Silicone tubes are linked with the actuators to a housing for damping. The actuators and the connection structure enable the plate to move in any direction on the tangential plane (Figure 1 (b)). A piece of sandpaper is placed on the plate to increase friction with a finger pad. A pin is connected to the bottom electromagnet, and it moves in a dorsal direction, and presses the finger pad (Figure 1 (c)).

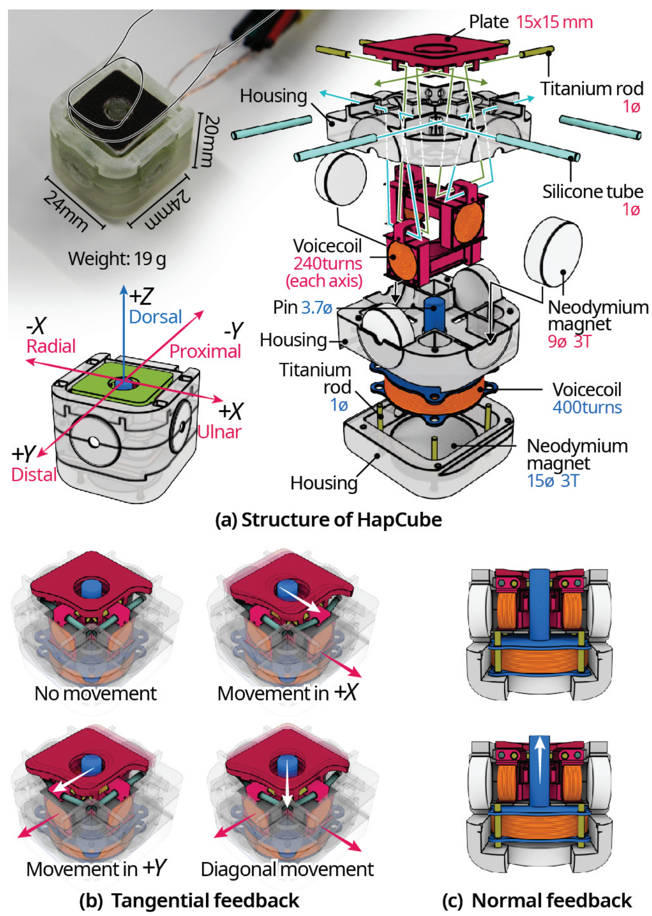

Figure 1: HapCube and its Structure (a). Tangential movement of the plate (b), and normal movement of the pin (c).

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2 PSEUDO-FORCE FEEDBACK DESIGN

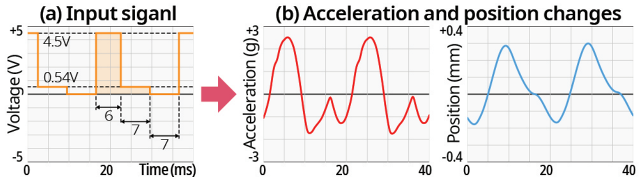

Figure 2: Input signal to create asymmetric vibration (a), and measured acceleration and position changes of the plate (b).

A tangential feedback is created by synthesizing two orthogonal asymmetric vibrations of the two voice coil actuators. Asymmetric vibration is an oscillation of moving fast in a positive direction and moving slow in a negative direction. In consequence, it stimulates human skin with asymmetrical strengths, and provides pulling sensation in the positive direction (pseudo-force feedback) [Amemiya et al. 2005; Rekimoto 2013]. Figure 2 (a) shows the input signal for generating the asymmetric vibration in axial directions. Its peak voltage (V_p) for axial directions is 4.5V. To generate the pseudo-force feedback in any angle (θ), the peak voltages for both electromagnets ($V_p x$ and $V_p y$) are determined by the following formula: $V_p x = V_p \times \sin\theta$, $V_p y = V_p \times \cos\theta$. Figure 2 (b) shows measured acceleration and position changes of the plate, which indicates that the input signal creates asymmetric vibration.

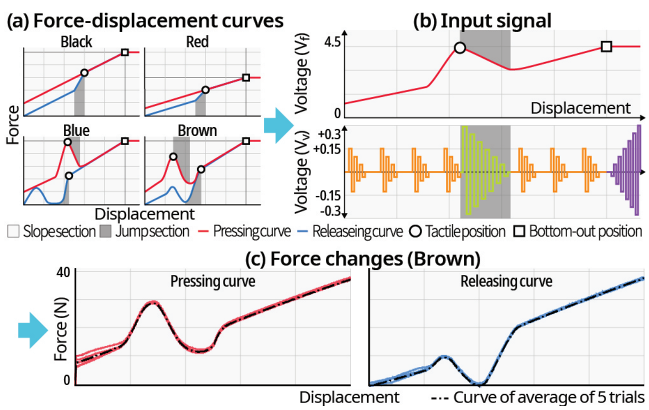

Figure 3: Force-displacement curves (a), input signal (b), and measured force changes of Brown virtual button (c).

A normal feedback of HapCube is designed to simulate various types of button feedback. Virtual button feedback is generated based on a force-displacement curve. In the Figure 3 (a) shows the force-displacement curves of the representative four key switches from CHERRY Company [CHERRY 2017]. The pin moves in a dorsal direction and applies force on the finger pad as the curves. In order to enhance the button feedback, the pin also vibrates depending on the slope section, the jump section, and the bottom-out position as shown in the Figure 3 [Kim et al. 2016; Kim and Lee 2013]. The force and vibrations are generated by sum of the two input signals (V_f and V_v in Figure 3 (b)) based on the force-displacement curves. The combination of the force and the vibration produces the normal button feedback. Figure 3 (c) shows measured force changes of Brown virtual button.

3 APPLICATIONS

In this section, we will introduce three applications developed for HapCube: haptic navigation, virtual button, and friction & texture.

3.1 Haptic Navigation

According to Kim et. al. [Kim et al. 2018], the range of angular just-noticeable differences (JNDs) for the tangential feedback of HapCube is 12.9-36.5°. HapCube is capable of directing minimum eight directions (45° intervals). We anticipate this feature to be able to provide a haptic navigation for vision or hearing impaired.

3.2 Virtual Button

We have simulated four virtual buttons using HapCube reproducing four types of CHERRY key switch within a correctness rate of 92.8% [Kim et al. 2016]. In a broaden context of use, the normal feedback of HapCube can manipulate various virtual button feedback using force-displacement curves. We anticipate that designers and developers would be able to produce dynamic quality of the virtual feedback using our data.

3.3 Friction & Texture

A number of researches have proposed about changing perceived texture of a surface (e.g., roughness, bumpiness) by applying vibrotactile cue on a surface and an object [Asano et al. 2015; Culbertson et al. 2013]; however these are limited for applying to the mid-air interface because of an absence of frictional force. HapCube enables to simulate a vibrotactile feedback (for texture) and a frictional force simultaneously. We anticipate to enrich the virtual/augmented reality experience with a lifelike haptic sensation.

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