Vibration Feedback Controlled by Intuitive Pressing in Virtual Reality

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***Abstract*—To provide more immersive experience in VR, high-fidelity vibrotactile feedback is one of the most important task to make VR user can feel virtual objects. In this work, we propose a mobile-based vibrotactile feedback system called FingerVIP, which provides an intuitive and efficient way for VR application/game designers to input proper vibration configuration of each target vibrotactile feedback. Our system uses pressure sensors attached on fingers as the controllers to manipulate the vibration configuration, including amplitude, frequency, and time duration. We utilized the proposed FingerVIP to set three kinds of vibrotactile feedback in a VR sports game and validated that FingerVIP successfully helped game designers reduce the number of iteration and the time for configuring vibration.**

***Index Terms*—haptic feedback, vibration, pressure, tactile, virtual reality**

I. Introduction

Vibrations have been widely used to provide haptic feedback in many human-computer interaction (HCI) systems as well as virtual reality (VR) applications. For examples, Krishna *et al.* [1] demonstrated a vibrotactile glove which can deliver seven facial expressions to visually impaired person. Spanlang *et al.* [2] considered VR with a simple haptic system as a useful tool for psychologists and neuroscientists to understand the Body Ownership Illusion (BOI) of participants. Meier *et al.* [3] investigated the feasibility of using vibrotactile onbody feedback to carry out pedestrian navigation. Xu *et al.* [4] designed a configurable, wearable sensing and feedback system for real-time postural balance and gait training. Breda *et al.* [5] studied the effects of using vibrotactile feedback in sports training. Recently, commercial haptic gloves such as HaptX [6] have integrated off-the-shelf vibration actuators to produce high-fidelity vibration feedback so that VR users can feel virtual objects.

Nowadays, with the advance of emerging technology, researchers have explored the feasibility of using VR to improve the sports training effectiveness [7], [8]. However, none of them investigated vibration feedback, which is important for the user to feel virtual objects and improve his/her imagery in VR sports training. Vibration feedback is especially important for basketball training in VR because the player cannot look at the virtual ball all the time when practicing the tactics or skills, but he/she still needs to immediately know whether the virtual ball touches the virtual hands so that he/she can take the next action.

(a) (b) (c)

Fig. 1. The three kinds of haptic sensations for basketball VR game. (a) Catching (b) Shooting (c) Dribbling

Although the hardware of vibration technology has been mature, we still lack an intuitive and efficient way to simulate and examine different vibration configurations (including amplitude, frequency, and time duration of vibration) in the application/game. Park et al. [9] tried to investigate the characteristics of widely used vibrations in terms of human perception, and suggested a design for developing software tools that facilitates the design of effective vibrations. However, setting proper vibration configurations to achieve multiple kinds of realistic vibrotactile feedback remains a challenging task. That is, application/game designers need to repeatedly adjust a vibration configurations through a user interface (UI) until the haptic sensation is well simulated by vibration sensors.

Nowadays, vibration configurations are typically entered via a keyboard or a mouse, which is inefficient especially when the VR application/game involves a variety of vibrotactile feedback. For example, in a basketball VR game, the haptic sensation of catching a ball, throwing a ball, and dribbling the ball (as shown in Fig. 1) is very different. Configuring a proper vibration for these three kinds of vibrotactile feedback via keyboard or mouse requires extensive effort, iterations, and time, not to mention that if the application involves, says, ten ore more kinds of vibrotactile feedback.

In this work, we propose a mobile-based vibrotactile feedback system named FingerVIP, which provides an intuitive and efficient way for the VR application/game designer to calibrate

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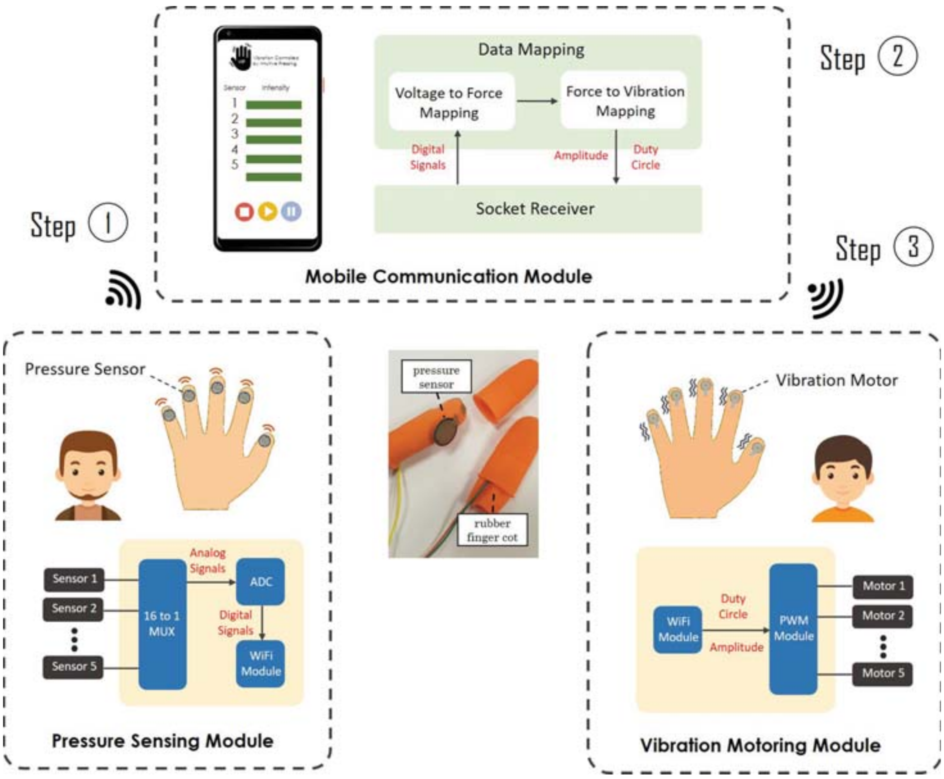


Fig. 2. The proposed FingerVIP mobile-based vibrotactile feedback system.

settings for different vibrotactile feedback. Our system uses pressure sensors attached on fingers as the controllers to manipulate the amplitude, frequency and time duration of vibration directly. The design of our system architecture is shown in Fig. 2. We took a basketball VR game as a test to investigate the efficiency of the proposed FingerVIP system. Results from a user study showed that FingerVIP successfully helped game designers reduce the number of iterations and time for adjusting vibration configurations for three kinds of haptic sensations.

II. System Architecture

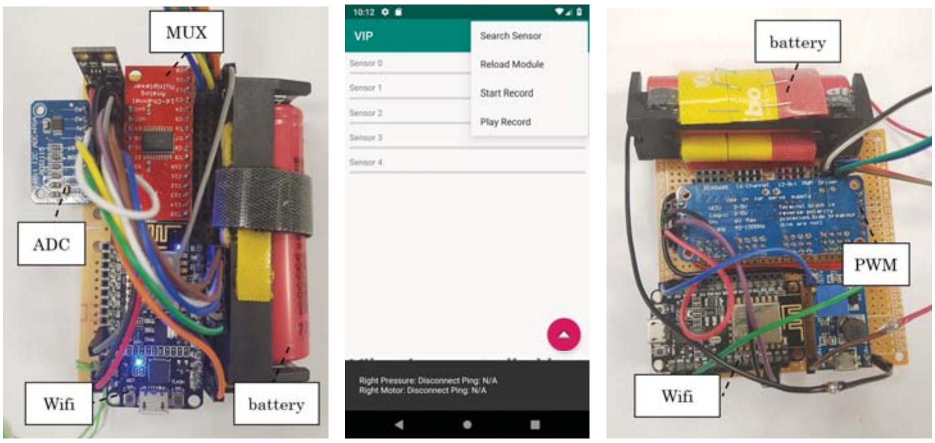
The aim of the proposed FingerVIP system is to provide an intuitive vibration control system to customize the vibrotactile feedback in VR or HCI applications. Our system architecture (as shown in Fig. 2) consists of three main components: a pressure sensing module, a mobile communication module, and a vibration motoring module. Considering the fidelity, power consumption, ease of use, and portability, we utilize pressure sensors to measure the human sense of touching real objects, and mimic similar senses of touch by using vibration motors. Moreover, a mobile phone is utilized to visualize the sensor data and bridge the communication between pressure sensors and vibration motors. In other words, the application/game designers can utilize the pressure sensing module to measure the human sense by touching the real object, while the application/game participants can sense the similar sense of touch via vibration motoring module.

A. Pressure Sensing Module

The pressure sensing module is composed of five pressure sensors and a pressure sensing circuit (cf. Fig. 3(a)). As shown in Fig. 2, each pressure sensor is attached on a rubber finger cot, and another finger cot is used as the outside cover to avoid accidentally moving the sensor. A multiplexer (MUX) is used to obtain the analog signals of pressure sensors, which are transformed to digital signals with an analog-to-digital converter (ADC). The pressure sensing module includes a Wifi chip to establish a connection with the mobile phone, and digital signals will be sent to the mobile phone through TPC Protocol per 100ms. A 3.7V battery is used as the power supply unit for the circuit. The Wifi chip and the lightweight stand alone battery enable the proposed FingerVIP system to be wearable.

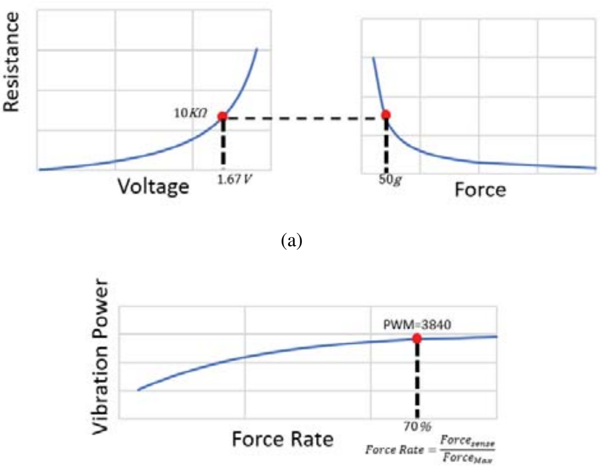
B. Mobile Connection Module

We developed an Android application (app) to provide users with several functionalities. The app bridges the pressure sensing module and the vibration motoring module. It can be used to record and play digital pressure signals. The mobile phone receives the digital signals of each pressure sensor and estimates the corresponding force magnitude by a linear mapping (cf. Fig. 4 (a)). The force magnitude is



(a) (b) (c)

Fig. 3. (a) The circuit of pressuring sensor module. (b) The screenshot of Android app. (c) The circuit of vibration motoring module.



(b)

Fig. 4. (a) The concept of linear mapping for force magnitude. (b) The concept of linear mapping for vibration amplitude.

further mapped to the amplitudes of vibration according to force rate (cf. Fig. 4 (b)). Fig. 3 (b) shows the interface of the app, which visualizes the mapped force magnitude for each pressure sensor. The app can utilize to scan the pressure sensing module and vibration motoring module establishing a Wifi connection. The apps also records the time duration of each continuous pressing. The vibration configurations, i.e., vibration amplitude, frequency, and time duration, are stored into a .tsv (Tab Separated Values) file and transmitted to the vibration motoring module.

C. Vibration Motoring Module

The design of the vibration motoring module is quite similar to that of the pressure sensing module. It contains five micro vibration motors and a circuit as shown in Fig. 3 (c). The vibration motoring module also has a Wifi chip to establishes a connection with the mobile phone for receiving vibration configuration files. Based on the vibration configurations, pulse-width modulation (PWM) is used for controlling the five micro vibration motors to give vibration feedback. We also use a 3.7V battery as a power supply for this module.

D. Operation Mode

FingerVIP provides two operation modes for the user. One is real-time vibration control, which means that all vibration motors are triggered immediately with their corresponding vibration patterns when the user gives forces on the pressure sensors to control the vibration motors. In this mode, the mobile phone establishes a Wifi connection to communicate with both the pressure sensing module and the vibration motoring module attached to the application/game designer (user) and the participant, respectively. The signals of pressure sensors are sensed, transformed from analog signals to digital signals, and then sent to the mobile phone to calculate the corresponding parameters for triggering the vibration motors in real-time. The other operation mode is off-time recording and playing. When recording, the mobile phone establishes a Wifi connection with only the pressure sensing module attached to the user. The user can record a multi-channel signal sequence sensed by the pressure sensors, and the recorded data are stored on the mobile phone as a configuration file, which can be used or merged with other configuration files later to create new vibration patterns. When playing, the mobile phone establishes a Wifi connection with only the vibration motoring module attached to the application/game participant. In this mode, the user can also specify a pressure sensor to record its signals separately, so that the user can focus on the vibration setting of a specific motor to provide more subtle vibrotactile feedback for application/game experiencer.

III. User Pilot Study

We recruited five participants to study the efficiency of the proposed FingerVIP system. At the beginning of the study, we

TABLE I
THE COMPARISON OF TIME (SECOND) AND ITERATION NUMBER FOR SETTING PROPER VIBROTACTILE FEEDBACK BY USING A TRADITIONAL MOUSE/KEYBOARD-INPUT UI PROPOSED BY [10] AND THE PROPOSED FINGERVIP SYSTEM.

Action	Method	Sub 1		Sub 2		Sub 3		Sub 4		Sub 5		Average	
		Time	Iter.	Time	Iter.	Time	Iter.	Time	Iter.	Time	Iter.	Time	Iter.
Catching	Traditional	118.10	3	137.17	3	72.55	2	199.31	3	394.98	3	184.42	2.8
	Proposed	8.26	1	14.63	1	9.08	1	11.37	1	4.66	2	9.6	1.2
Shooting	Traditional	231.22	5	81.70	2	249.97	2	197.86	3	359.54	2	224.06	2.8
	Proposed	46.39	2	16.68	2	27.21	2	18.37	2	11.09	2	23.95	2
Dribbling	Traditional	157.50	3	181.92	3	154.66	2	121.85	1	442.38	2	211.66	2.2
	Proposed	39.01	2	19.01	2	32.76	2	20.21	2	12.24	2	24.64	2

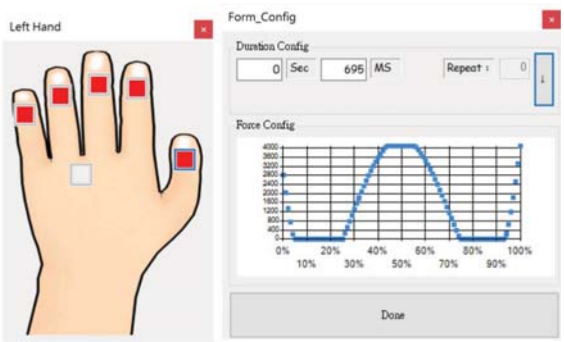


Fig. 5. The vibration setting UI proposed by [10]

briefly introduced the proposed system and explained the goal of the study to the participants. In additional, each participant was asked to perform three actions, i.e., catch, shoot, and dribble a real basketball, to experience the corresponding haptic sensations. In the next phase, each participant was asked to simulate the similar vibrotactile feedback for these three actions by two ways: (1) by using an traditional UI (cf. Fig. 5) input with a mouse and/or a keyboard, and (2) by using the proposed FingerVIP system. To compare the efficiency of the two ways for inputting proper vibration configurations, we recorded the number of iterations and the time duration that each participant used to set a satisfactory vibrotactile feedback. The results in Table I shows that by using our proposed FingerVIP system, every participant took less time and iterations to set a satisfactory vibrotactile feedback for each action. Averagely, the shooting and the dribbling actions require more time/iterations because the haptic sensations of these two actions are more complex. All participants agreed that the proposed FingerVIP system is more intuitive for configuring vibrotactile feedbacks.

IV. CONCLUSION AND FUTURE WORK

We propose FingerVIP, a mobile-based vibrotactile feedback system that provide an intuitive and efficient way configuring proper vibration of target vibrotactile feedback for VR/HCI applications. The FingerVIP system uses pressure sensors attached on fingers as controllers to manipulate the configurations of the vibration motors. Results from a user study showed that users could successfully configure three kinds of vibrotactile feedback in a basketball VR game with fewer iterations and less time using FingerVIP. In the near future, we will integrate our system with Unity and Unreal Engine so that the VR game designers can easily configure vibration while designing vibrotactile feedbacks. Moreover, we will apply AI technology to construct more accurate mapping curve of vibration amplitude for various applications.

V. ACKNOWLEDGEMENT

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