Interacting with the virtual reality: rendering of pressure, textures, and making/break contact sensations via fingertip wearable haptic devices

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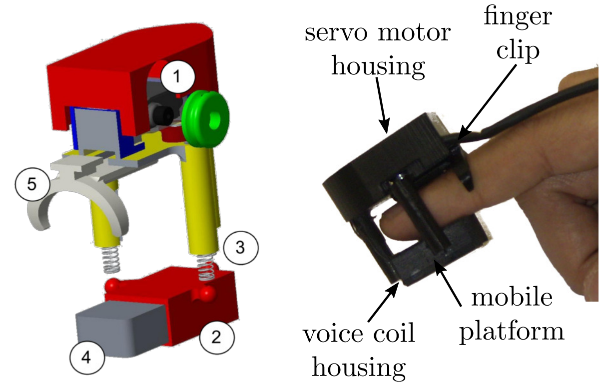
***Abstract*— Head-mounted displays, such as the Oculus Rift, and unobtrusive tracking systems, such as the Leap Motion, are making Virtual Reality (VR) experiences increasingly immersive and engaging. Wearable haptic devices are recently gaining great popularity among researchers. Such interfaces will indeed enable natural forms of communication between the wearer and the VR environment.**

This work presents a novel wearable haptic system for immersive virtual reality interactive experiences. Each wearable device is composed of two platforms: one placed on the nail side of the finger and one in contact with the finger pad, connected by three cables. One small servomotor controls the length of the cables, thus being able to move the platform towards or away from the fingertip. One voice coil actuator embedded in the platform provides vibrotactile stimuli to the user.



(a) (b)

Fig. 1. The wearable cutaneous device can provide the sensation of making/breaking contact with virtual objects, provide variable pressure, and render different textures.

I. INTRODUCTION

Wearable haptics is recently attracting great attention in the fields of robotics, haptics, and mechanical engineering. Being able to provide effective haptic stimuli through lightweight, inexpensive, and unobtrusive devices can significantly enlarge the applications of haptic systems to new and exciting fields, such as gaming, rehabilitation, and remote maintenance. Recently, we have also seen a few start-up companies taking up this challenge and start developing wearable haptic devices for the fingertips. For example, Tactai (USA) has presented a fingertip wearable haptic device able to render pressure, texture, and the sensation of making and breaking contact with virtual objects [1], [2]. It can apply up to 6 N to the fingertip, and it weighs 29 g for 75×55×30 mm dimensions. In Europe, GoTouchVR (France) developed a 1-DoF wearable device equipped with a mobile platform able to apply pressure and make/break contact with the fingertip. It can exert up to 1.5 N on the skin, it weighs 40 g for 50×12×30 mm dimensions, it is wireless, and the battery guarantees up to 2 hours of playtime. These companies have also already been showing demonstrations of their wearable haptics systems featuring immersive environments displayed through these virtual reality headsets [2], [3]. For example, at CES 2017, TACTAI showed their device in a virtual reality application, using an Oculus Rift to render the scene and a Leap Motion controller for fingertip tracking. At the same conference, GoTouchVR showed their device in a virtual reality application, using an Oculus Rift to render the scene and a Leap Motion controller for fingertip tracking. More recently, also our group at the University of Siena started a company that develops wearable haptic devices: WEART. Also in the literature we can find several examples of wearable devices for the fingertips. The challenge is to be able to provide effective stimuli while guaranteeing a high wearability, ergonomy, and low power consumption and cost. Pacchierotti et al. [4] have recently presented a review paper on wearable haptic devices for the fingertip and the hand, discussing also general guidelines for the development of such interfaces.

II. DEVICE DESCRIPTION

In this work, we present a novel low-cost wearable haptic device for cutaneous stimulation, inspired from [5] and improved following the design guidelines of [4]. It is shown in Fig. 1b, while a CAD sketch is shown in Fig. 1a. It is composed of a static upper body and a mobile end-effector. The upper body is located on the nail side of the finger, supporting one small servo motor (indicated with ① in Fig. 1a), and the mobile end-effector is in contact with the finger pad ②. The two parts are connected by three cables ③ attached to the motor pulley, making the platform able to move towards or away from the fingertip.

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As a consequence, a variable pressure is provided directly to the user's fingertip to recreate the sensation of making and breaking contact with virtual objects. The end-effector platform houses a voice coil actuator (4) enabling the device to provide vibrotactile stimuli for texture rendering. Finally, a clip system (5) enables the user to easily fasten the device on the finger. The device is realized in Acrylonitrile Butadiene Styrene (ABS-Plus, Stratasys, USA) through the use of a commercial 3D printer. The servomotor is PWM-controlled and can provide a maximum torque of 0,8 kg·cm. To render the texture of the virtual sufaces we used the The Penn Haptic Texture Toolkit (HaTT). The HaTT [6] includes 100 haptic texture and friction models. It was developed to provide haptics researchers with a method enabling the validation of their texture modeling and rendering methods. Thanks to this method, we were able to enrich our interaction with a compelling texture rendering, significantly improving the immersiveness of the user's experience.

The proposed device weighs 23 g, the platform has a vertical displacement up to 20 mm and can render a normal force up to 8 N. Each device is connected to a wrist bracelet, connected to an external computer via bluetooth. The bracelet, able to control up to 5 fingertip devices at a time, houses the controller and the audio amplifiers for the voice coil actuators. With respect to the wearable devices presented in [5], [7], this device weighs less, is more compact, and can also render the textures of virtual objects and/or other vibrotactile stimuli related with specific events during the interaction (e.g., making/breaking the contact with the objects).

III. DEVICE TEST

At this stage of the work, only a preliminary (and qualitative) validation of the system has been carried out. We asked ten participants to use the proposed haptic system in a virtual reality scenario (see the attached video). The experimental setup is shown in Fig. 2. A virtual environment was developed using the game engine Unity, including several object (of different materials) with which the user could interact: four soda cans, a wooden log, and a baseball. The users wore a VR headset (Oculus Rift) and three fingertip devices on their right hand. The movements of the user hands were tracked by a Leap Motion sensor (mounted on the headset) during the interaction with the virtual environment. A hand model was rendered in the virtual environment, mimicking the user's hand pose. A mass-spring-damper model was then used to compute the interaction forces arising from the contact of the hand with the virtual environment. Our devices were used to render these forces (through the algorithm presented in [7], [8]), along with texture-related vibrotactile stimuli (through the algorithm presented in [6]), providing the user with the sensation of touching and grasping the objects in the scene.

At the end of the experiment, subjects rated their experience, evaluating the effectiveness of the provided feedback and the level of comfort of the device. The scores were given using a slider ranging from 0 (meaning "very low") to 10 (meaning "very high"). The feedback was rated 8.3 out of 10, while the comfort of the system rated 7.9 out of 10. We have also proposed a hands-on demonstration of this system.

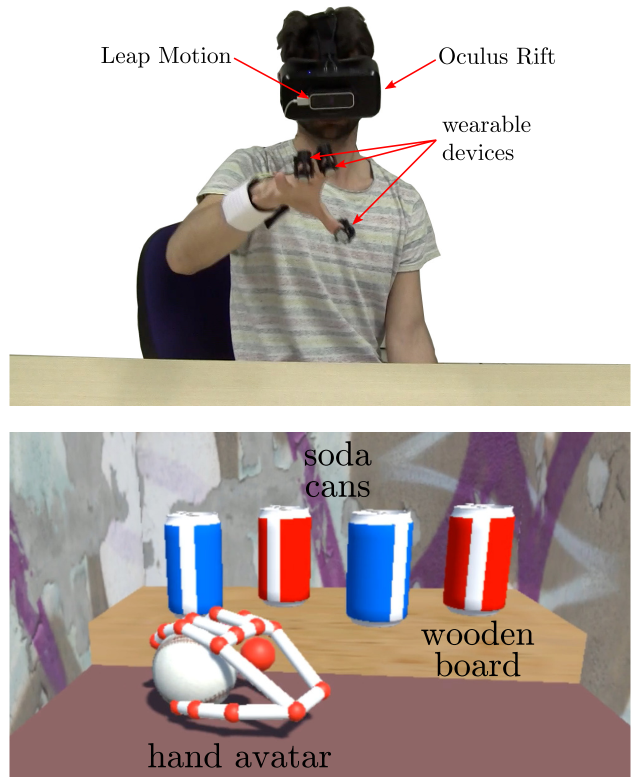

Fig. 2. Wearable haptics system for Virtual Reality. A Leap Motion track the motion of the fingertips, a hand avatar mimick the motion of the hand, and three fingertip wearable tactile devices provide the user with pressure stimuli, the sensation of making/breaking contact with virtual objects, and texture rendering.

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