Using the Leap Motion Controller for Hand Tracking and Wearable Haptic Devices for Contact Rendering

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I. Introduction

The complexity of the world around us is creating a demand for novel interfaces that will simplify and enhance the way we interact with the environment. The recently unveiled Android Wear operating system address this demand by providing a modern operating system for all those companies that are now developing wearable devices, also known as "wearables". There is the Google Moto 360, the Asus ZenWatch, the Apple Watch, and many more are being presented every year. The wearable electronics business has powered over $14 billion in 2014, and it is estimated to power over $70 billion by 2024. This market stems from the need for wearability, which is a key element for a natural interaction with nowadays technology. Wearability of robotic devices will enable novel forms of human intention recognition through haptic signals and novel forms of communication and cooperation between humans and robots. Specifically, wearable haptics will enable devices to communicate with humans during their interaction with the environment they share.

Wearable haptic technology have been introduced in our everyday life by Sony. In 1997 its DualShock controller for PlayStation revolutionized the gaming industry by introducing a simple but effective vibrotactile feedback. More recently, Apple unveiled the Apple Watch, which embeds a linear actuator that can make the watch vibrate. It is used whenever the wearer receives an alert or notification, or to communicate with other Apple Watch owners. You can get someone's attention with a gentle vibration, or even send some personal information like your heartbeat.

However, the force feedback provided by these popular devices is still limited to vibrations, reducing the possibility of simulating any rich contact interaction. Towards a more realistic feeling of interacting with virtual and remote objects, researchers focused on glove-type haptic displays such as the Rutgers Master II and the CyberGrasp, which provide force sensations to all the fingers of the hand simultaneously. However, although they provide a compelling force feedback, these displays are still complex and *very* expensive. For this reason it becomes crucial to find a trade-off between a realistic feeling of touch and cost/wearability of the system. In this regard, we found *tactile technologies* very promising. Tactile devices are haptic interfaces able to provide tactile force feedback only. This property makes possible to dramatically simplify their form factor and, at the same time, provide a compelling and realistic feeling of touching virtual objects [1], [2], [3].

II. Contribution

This paper presents a novel haptic system for immersive virtual reality interaction. It enables a human user to naturally interact with a virtual environment while being provided with compelling cutaneous haptic feedback about contacts with the virtual objects. The system consists of a Leap Motion controller and five wearable tactile devices.

1) Leap Motion: The Leap Motion controller is a small USB peripheral device that uses two monochromatic IR cameras and three infrared LEDs to track the position of the fingertips in 3-D space. It observes a hemispherical area up to a distance of 1 m with an accuracy up to 0.01 mm [4].

2) Wearable device: Each wearable tactile device is composed of two platforms: one placed on the nail side of the finger and one in contact with the finger pulp, connected by three cables (Fig. 1b). One small servomotor controls the length of the cables, thus being able to move the platform towards or away from the fingertip. As a consequence, a normal force can be displayed at the user's fingertip. Each device is connected to a wrist bracelet that provides power and wireless connection to an external computer. This device is a simplified 1-DoF version of the cutaneous display presented in [5]. With respect to our previous haptic virtual reality system [6], we greatly improved the form-factor of the wearable devices employed. This allows us to easily track up to five wearable tactile devices (see Fig. 1).

The force to be provided was estimated according to a static elastic model of a hemispherical soft fingertip undergoing large contact deformation, as occurs when hands handle and manipulate objects through the fingertips. In order to simplify the model, we considered a linear relationship between resultant wrench at the fingertip and device's platform displacement, similarly to [2], [7]. Since in this work we employed 1-DoF cutaneous devices, we considered only the contact forces applied normally to the fingerpad.

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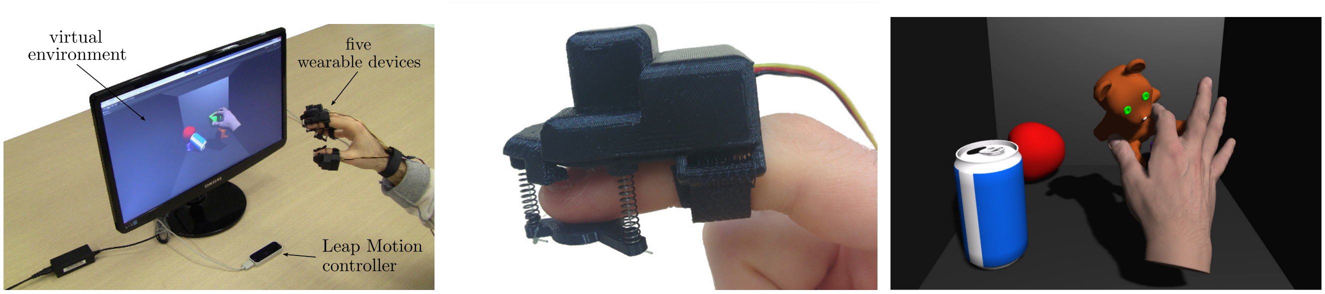

(a) 1-DoF wearable haptic device (b) Experimental setup (c) Virtual environment

Fig. 1. Immersive tactile interaction in a virtual environment. User's fingertips are tracked using a Leap Motion controller (a) while five wearable tactile interfaces (b) provide the human operator with the compelling illusion of touching a virtual object (c).

III. Experimental evaluation

We validated our immersive system in the virtual reality scenario shown in Fig. 1c. It is composed of four virtual objects: a dice, a teddy bear, a soda can, and a ball.

Six participants took part in the experiment, including 2 women and 4 men. Two of them had previous experience with haptic interfaces. None of the participants reported any deficiencies in their visual or haptic perception abilities, and all of them were right-hand dominant. The experimenter explained the procedures and spent about two minutes adjusting the setup to be comfortable before the subject began the experiment.

Subjects were asked to wear five tactile devices on one hand. The task consisted of picking up the teddy bear, placing it on top of the dice, picking up the ball, and striking the soda can with it. A video of the task can be found at http://goo.gl/arYQmD. The position of the five fingertips wearing the cutaneous devices were tracked using the Leap Motion controller. In order to increase the illusion of telepresence, a virtual human hand mimicked the user's hand pose in the virtual environment. Every time the hand came in contact with a virtual object, the wearable tactile devices applied a suitable amount of force to the users' fingertips, providing them with the compelling sensation of *touching* the virtual environment.

Subjects were asked to complete the above mentioned task either with force feedback or not. In the condition where no force feedback was provided, subjects were required to remove the devices and interact with the virtual environment barehanded. At the end of the experience, participants were asked to fill in a 6-item questionnaire using bipolar Likert-type seven-point scales. It contained a set of assertions, where a score of 7 was described as *completely agree* and a score of 1 as *completely disagree* with the assertion. It was divided in two sections considering (i) the realism of the interaction and (ii) the wearability of the system. Participants considered the system wearable and very easy to wear. Moreover, they found the cutaneous feedback natural and compelling. The cutaneous tactile information was considered paramount towards a realistic experience and the condition with force feedback scored significantly higher than the one without force feedback.

IV. Conclusion and future work

The proposed tactile system is extremely wearable, effective, inexpensive, and completely wireless. There are in fact no workspace restrictions apart from the ones related to the gesture recognition technique. A further investigation is required to compare the performance, in terms of telepresence and user experience, between 1-DoF cutaneous displays (as used here) with respect to 2-DoF and 3-DoF devices (as in [1], [2], [3]). Moreover, we are planning to improve the design of our cutaneous displays by adding a vibrotactile actuator, that will be in charge of rendering additional features, such as the object's texture.

We strongly believe that this kind of highly-wearable devices can be useful in many applications, ranging from rehabilitation to entertainment purposes, from robotic surgery to e-commerce, and will contribute in bringing haptic technologies to everyday-life applications. It is worth underlying that the device presented provides tactile stimuli only, while most of the kinesthetic feedback is missing. Possible solutions to compensate for this lack of information, while preserving the portability of the device, are currently being investigated.

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