Wearable Haptics and Hand Tracking via an RGB-D Camera for Immersive Tactile Experiences*

Leonardo Meli[1,2], Stefano Scheggi[1], Claudio Pacchierotti[1,2], Domenico Prattichizzo[1,2†]

[1] Dept. of Information Engineering and Mathematics, University of Siena, Siena, Italy. [2] Dept. of Advanced Robotics, Istituto Italiano di Tecnologia, Genova, Italy.

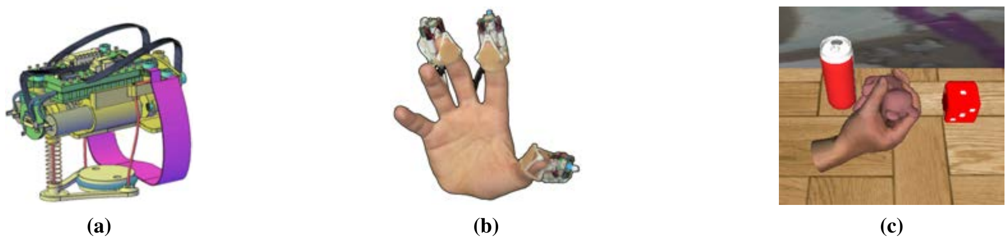

Figure 1: *Tactile interaction in a virtual environment. User's fingertips are tracked using an RGB-D camera, while three wearable haptic interfaces (a)-(b) provide the human operator with the compelling illusion of touching a virtual object (c).*

1 Introduction

In 1997 Sony revolutionized the gaming industry by introducing a simple but effective vibrotactile feedback in its DualShock controller for PlayStation. By 2013, more than 400M units have been sold. Nowadays, the game interface Wii Remote motion controller provides a similar feature, but wirelessly, and can be considered the most popular portable haptic interface, with over 100M sales. However, its force feedback is still limited to vibrations, reducing the possibility of simulating any rich contact interaction with virtual and remote environments. Towards a more realistic feeling of interacting with virtual 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 complex and very expensive - the CyberGrasp, for instance, costs more than 60,000 US dollars!

Thus, it becomes crucial to find a trade-off between a realistic feeling of touch and cost/portability of the system. In this regard, we found *tactile technologies* very promising. Tactile devices are haptic interfaces able to provide tactile force feedback only (they do not provide any kind of kinesthetic force). This property makes possible to dramatically simplify their form factor and provide a compelling and realistic feeling of touching virtual objects [Pacchierotti et al. 2014].

2 Contribution

In this work we present a wearable and portable fingertip tactile device for immersive virtual reality interaction. It consists of two platforms: one fixed to the back of the finger and one in contact with the fingertip, connected by three cables (see Fig. 1a). Three small electrical motors, equipped with position encoders, control the length of the cables, thus being able to tilt and move the platform towards or away from the fingertip. As a consequence, a 3-D force can be displayed to the user. The force to be provided was estimated according to a mathematical model of the finger, which considered a linear relationship between resultant wrench at the fingertip and device's platform displacement. Each device has to be connected to a wrist bracelet, providing power and wireless connection to an external computer. Up to five devices can be connected to a single bracelet, thus providing a flexible and modular solution as depicted in Fig. 1b. We validated this tactile interface in a virtual reality scenario (see Fig. 1c). Users were asked to wear three tactile devices on one hand and interact with different virtual objects. The hand pose was tracked using a model based hand tracker via an RGB-D camera [Oikonomidis et al. 2011]. A virtual hand [Šarić 2011] mimicked the user's hand pose. As soon as the hand came in contact with a virtual object, the tactile devices applied the requested force to the users' fingertips, providing them with the compelling sensation of *touching* the virtual environment. The proposed tactile system is extremely portable, cost-effective and completely wireless (there are virtually no workspace restrictions apart from the ones related to the gesture recognition technique). A representative video can be found at http://goo.gl/t25yc8.

Experiment. Ten participants tried our immersive virtual reality system. They were asked to wear the three tactile devices and interact with the virtual environment for 10 minutes: first with no force feedback (tactile devices switched off) and then with force feedback. Participants were then 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 portability of the system. Participants considered the system portable and very easy to wear. Moreover, they found the tactile feedback natural and compelling. The tactile information was considered paramount towards a realistic experience.

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†e-mail:{meli, scheggi, pacchierotti, prattichizzo}@dii.unisi.it

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