Enabling wearable soft tactile displays with electroactive smart elastomers

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1 Introduction

The use of virtual images, computer generated objects and 3D models is becoming increasingly relevant in a number of fields such as simulators for training of medical operator [1], teleoperation [2], computer aided design and 3D modelling [3]. For instance, virtual reality can help training surgeons, reducing the need for learning and practicing entirely with patients or animals[4]. To this aim, data from body scans in three dimensions (3D) already allows for excellent virtual renderings of the surgical scene [5]. Nevertheless, the excellent visual feedback that can be generated is not sufficient to generate a truly realistic virtual experience. Indeed, visual feedback has to be complemented with tactile feedback, via wearable tactile displays allowing users to appreciate differences in compliance of different virtual tissues.

Commercial interfaces, capable of providing users with tactile feedback, are currently available. For example, the grounded interface Geomagic Touch (Geomagic, Inc, USA) is accurate and can produce considerable forces, even though it is far from being wearable [6]. The hand-grounded CyberGraspTM system can provide force feedback to the five fingers [7]; however, its complex mechanics, made of tendons routed via an exoskeleton and the need for an external actuator module, limit its portability [6]. The CyberTouchTM is designed to add a tactile feedback to the system, but as many other similar devices, it works only in vibration mode [8].

Aimed at overcoming limitations of such devices, Scilingo et al. proposed a display of variable compliance aimed at integrating kinesthetic and tactile information [9]. Minamizawa et al. presented the gravity grabber: a wearable and portable tactile display consisting of two motors fixed on the back of the finger and a belt able to apply force to the user's finger pulp [10]. Tactile stimulators based on electrical motors were also described by Prattichizzo et al. [11]

adfa, p. 1, 2011.

Despite these advances, to the best of our knowledge, no tactile devices are currently available to mimic virtual contacts (of multiple fingers) with soft bodies, via soft interfaces. We believe that a soft interface is needed in order to ensure that the compliance of the display conforms to the deformable finger pulp, so as to improve the tactile perception. Moreover, a device conceived to that purpose should allow the user to freely explore the virtual environment. Therefore, such tactile systems should be wearable and compact, and should have a light weight and a simple structure (with no gearings) so as to fit on the fingertip and to allow mobility to the fingers, the hand and the arm. Furthermore, they should also be acoustically silent and generate low heat, so as to favour comfort for the user.

Our approach, aimed at realistically simulating the tactile interaction with soft bodies, consist of using the technology known as dielectric elastomer actuators (DEAs). DEAs represent one of the most promising smart material technologies for soft actuation. They consist of thin layers of soft insulating elastomers, coated with compliant electrodes, that can be electrostatically deformed upon electrical charging [12-14].

Here, we describe hardware and software architectures that we have conceived and developed to use the DEA technology to allow users to interact with virtual soft bodies via multiple fingers. This is done by using a custom-made tactile display that we have originally designed and prototyped, combined with a commercial optical tracking system for the spatial position of fingers, and a virtual environment developed for this purpose. By means of multiple finger interactions, users are expected to explore virtual soft objects in an intuitive, natural and accurate fashion.

2 Materials and methods

2.1 The tactile display technology

The tactile display was conceived using the technology known as hydrostatically coupled DEAs (HC-DEAs), developed by our group [12]. It relies on an incompressible fluid that hydrostatically couples a DEA-based active membrane to a passive membrane that is in contact with the user's fingertip (Fig. 1). When a voltage is applied to the active membrane, the occurring surface expansion makes it to buckle outwards, while the passive membrane follows inwards [15]. This principle allows for an electrically safe and tuneable transmission of force to the finger, as preliminarily demonstrated already by our group [16] (Fig. 1).

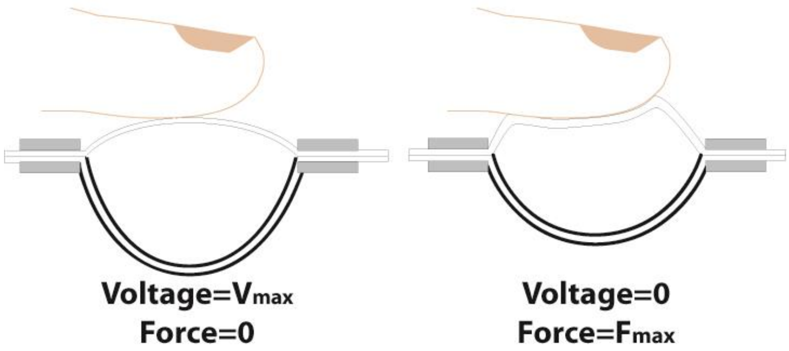

Fig. 1. Schematic drawings of the interaction between the finger and the soft tactile display.

The HC-DEA is integrated within a plastic case arranged at the fingertip so as to keep the finger pulp is in contact with the passive membrane of the actuator. The active membrane is protected by a plastic chamber so as to avoid any contact with the user's fingers (Fig. 2).

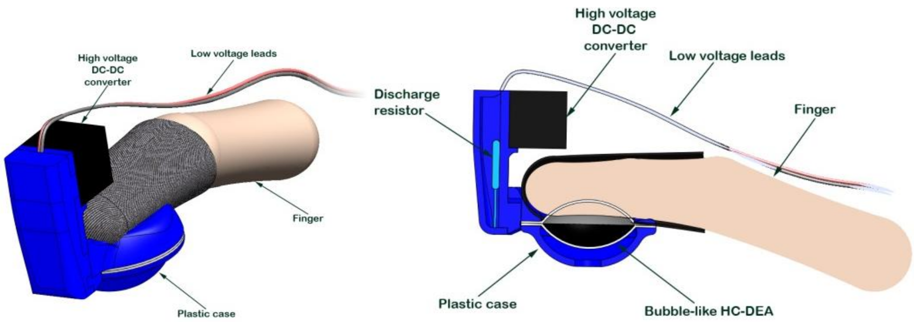

Fig. 2. Schematic drawings of the finger-tip wearable tactile display

The figure also shows the miniaturized DC-DC converter (EMCO Q50, EMCO High Voltage, USA) and the high-voltage discharge resistor required to provide the high voltage input for the actuator. The display's mechanical response has been demonstrated to be able to provide users with tactile stimuli that could be properly perceived [16].

2.2 Optical tracking system for the spatial position of fingers

We obtain user fingertip location data by using a commercial optical hand tracking system: Leap Motion [17] (Fig. 3).

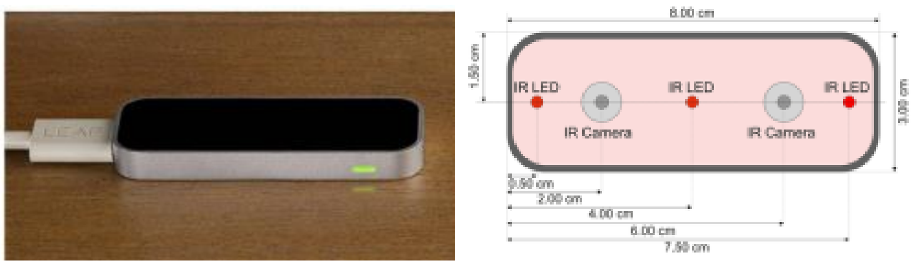

Fig. 3. Leap Motion controller (left); Leap motion schematic view (right).

Although there are a number of systems developed for the purpose of tracking fingertip locations in 3D space, such as the Kinect by Microsoft and the Duo MLX by Code laboratories [REFFF added at end]. We decided to use the Leap motion system as it is a nonintrusive optical system that is reasonably accurate, very compact and very cost-effective, and which also offers simple and supported implementation libraries for the Java programming language. However, the main issue that we had to face with this system was that our wearable fingertip tactile display occluded the fingertips to the system's stereo infrared camera, making it unable to accurately determine the fingertip location. First preliminary tests were conducted programming the Leap motion to detect the palm of the hand. This allowed us to represent just a single finger within the virtual environment (Fig. 4).

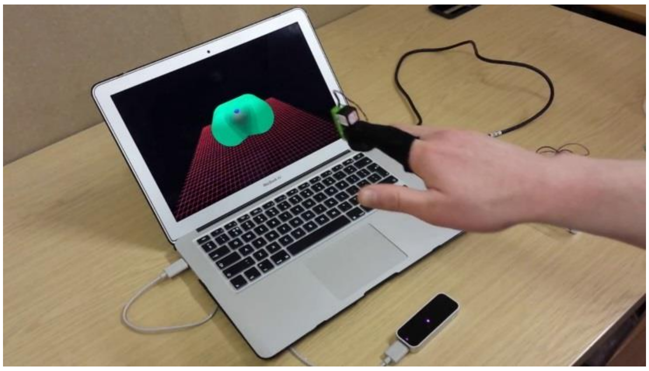

Fig. 4. Experimental Setup

2.3 Software architecture

To create haptic interactions as response to user inputs within a simulated virtual environment, there's the need for a system capable of performing the following steps:

log the movements of the user, represent the position data within a virtual coordinate system, detect a collision between represented movement of the user and a virtual object, compute an appropriate response based on this interaction and then convey this information on the haptic rendering device to be perceived by the user. In this section we will outline the system we implemented to test our wearable multi-fingered tactile device for interactions with virtual soft bodies.

To construct the virtual environment, the programming language Java was employed along with the OpenGL graphics Library. The reason for choosing Java over other languages such as C++ was that the combination of Java and OpenGL caters for rapid development of three-dimensional virtual environments that can be rendered graphically at reasonable speeds, as well as catering for simple implementation of serial communication with external microcontrollers and data from the Leap motion hand tracking system.

In the environment we created, user fingertip location was simplified to a single spherical point in a three-dimensional space with no normal vector. This greatly simplified the collision detection algorithm and allowed for our non-optimised programme to run at higher speeds.

As soon as a collision was detected the programme generated a force response that was rendered to the finger interacting with the virtual soft body model. This force response was proportional to the distance of infringement of the finger through the soft body model. This force response was then sent via a serial connection to an external microcontroller/ control interface, described below. The virtual environment that we developed for testing our fingertip tactile display enabled us to create virtual soft body objects with variable properties. This predominantly concerned the maximum force that can be applied from interacting with the virtual object, and the rate in which pressure is applied to a users fingertip through contact and penetration distance of virtual soft body object.

2.4 Control hardware

An Arduino Uno was used as the external control interface for our haptic device. The message sent to the Arduino instructed how much voltage to output from one of the Pulse Width Modulated (PWM) pins. As the Arduino can only output PWM voltages, a capacitor resistor smoothing circuit was employed. This smoothed signal voltage then controlled a buffer reader, which controlled the amount of voltage being transferred to a low-to-high voltage converter (EMCO Q50, EMCO High Voltage, USA), which was used to drive the HC-DEA display. The device converted 0-4V inputs to 0-4kV outputs. This driving voltage was required to deform the HC-DEA active membrane, which then stimulated the user’s fingertip.

3 Results

In our current demonstration users can probe a soft body object with one finger, which, as mentioned before, is represented as a coloured sphere. Our soft body object is composed of an array of deformable spheres. When the sphere that represent the fingertip position comes into contact with one or more of the soft body object spheres, the soft body object spheres deform by shrinking in an axes parallel to that of the centre of the soft body sphere and the point of collision, as well as changing colour from green to red. This creates a visual cue informing the user that there is a collision between the representations of the user's fingertip and the virtual soft body object.

4 Conclusions and future developments

In this work we presented work in progress towards the integration of a tactile display made of DEA into a multi modal virtual reality environment for interactions with soft bodies. The proposed actuation technology offers several advantages over conventional technologies, allowing for compact, wearable and lightweight actuators capable of providing electrically controllable tactile stimuli via soft interfaces.

While the proposed display demonstrated to be effective, both the casing and the actuator size were not optimized for the application. In the next iteration of our wearable haptic device we will be reshaped, reducing the actuator size, so as to mimic the shape of the finger allowing for a multi finger tracking (Fig 5).

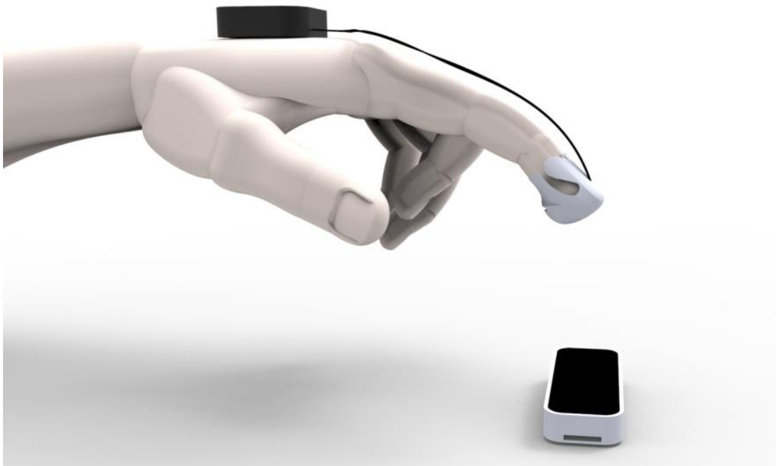

Fig. 5. Rendering of the next iteration of the system

The high voltage circuitry will be arranged on the top of the hand so as to further optimize the shape. This will make our haptic device easily implementable within applications that currently use the Leap motion and also some other non-marker optical motion tracking solutions such as the Xbox Kinect, perhaps one of the most pervasive ‘off the shelf’ motion tracking systems

In future iterations of the software used to test our wearable tactile display, we will utilise C++ with general purpose haptic rendering libraries such as CHAI 3D (Conti et al, 2005) and H3DAPI (Sense Graphics, 2014) as these libraries have been optimised for rendering more complex virtual scenes on haptic devices and graphical displays.

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