Rendering softness: a new fabric yielding display

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Abstract

In this paper we present a new bi-elastic fabric-based display for rendering softness. It consists of a thin layer of bi-elastic fabric placed on the top of a hollow cylinder and tied to an external circular crown which can run outside over the cylinder. The crown can be moved upward and downward by means of a DC motor. The crown is connected to the female screw by means of four supports which slide along suitable loops. When the motor pulls down the crown, the fabric is stretched and its apparent stiffness increases. Conversely, when the motor pushes up the crown the fabric is relaxed and it feels softer. Subjects can touch the fabric and feel different levels of softness according to the stretching induced by the motor. Being the fabric deformable in a controlled way under the fingerpad, this new device is able to provide cues for a more reliable and realistic perception.

Figure 1: The FYD system.

1 Introduction

Haptic perception allows to explore and recognize an object by conveying several physical information to mechano-receptors and thermo-receptors lying into our skin throughout the body. The term "haptic" is usually referred to eliciting both kinaesthetic and cutaneous channels. In some cases kinaesthesia can play a more relevant role in discriminating physical or geometrical features rather than cutaneous information, and in other the role is symmetrically exchanged. For instance, while weight is dominated by kinesthesia, thermal sensations are purely cutaneous. However, both are necessary to have a fine and reliable perception of the reality, even if the cutaneous cues are generally predominant [7].

In addition to recent haptic displays ([5]) which focused on providing cutaneous cues, it is worthwhile mentioning other surrogating detailed contact shape information with information on the contact area on the fingertip and its changes with varying contact force (see e.g. [2, 4]). Although all these displays are capable of rendering a reliable softness sensation, there are still some technical limitations due to low resolution of stimuli. Here we propose a new device which conveys to subjects both cutaneous and kinaesthetic information by exploiting the bi-elasticity of a fabric. Bi-elastic means that the fabric exhibits properties which render it elastic in at least two substantially perpendicular directions, and preferably in all directions. Subjects can push whit their finger over a bi-elastic fabric which can be stretched by a suitable DC motor-based system. Different levels of stretching render different elasticity perception. The architecture of the new device implies also an estimation of the contact area over the fingerpad. Each level of elasticity can be associated with a specific force-displacement and force-area behaviour. This current architecture of the device does not allow decoupling cutaneous and kinaesthetic information rendering, but however provides the subjects with more reliable and realistic tactile perception. The authors, in previous works [2] already proposed a haptic device, whose acronymous is CASR, which provided specific force-displacement and force-area profiles. In contrast to the old device, the new one does not present edge effects due to discontinuity of the cylinders as well as the contact area perception is more realistic. Further works [6] aimed at integrating the CASR with a commercial Delta Haptic Device in order to increase performance.

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2 Equipment description

The system here proposed, which hereinafter we will call FYD (Fabric Yielding Display), is based on a layer of bi-elastic fabric which can be touched by subjects with their forefinger. By changing the elasticity of the fabric, subjects are able to feel different levels of stiffness (see fig. 1). It is comprised of a hollow plastic cylinder containing a DC motor. A thin layer of bi-elastic rectangular-shaped fabric is placed on the top of the hollow cylinder and it is tied to a circular crown which can run outside along the cylinder. A schematic view of the display is reported in fig.2. Several materials (including commercial lycra, latex layer, and silicon rubber) were tested to verify their suitability for our purpose. Best performance were provided by Superbiflex HN by Mectex[1] because it exhibits both a very good elastic behaviour with a large range of elasticity and a high resistance to traction. A screw is jointly connected to the axis of the motor while a female screw is attached to the crown by means of four supports. The motor is controlled using a Sabertooth Syren10 dual motor driver. This driver allows to get a bidirectional rotation of the motor, if the input voltage is appropriately chosen. Using the National DAQ system PCI6036E, we can acquire the position of the crown with an external potentiometer connected to it, and, consequently, set the input voltage for the motor in order to reach the desired position, i.e. the desired stretching state of the fabric. The rotational movement of the motor is converted by the female screw into a translational movement of the crown. The up/downward movement of the crown produces relaxation or stretching of the fabric with a consequent change in stiffness of the fabric itself. This stiffness modulation is exploited to convey to subjects, who touch the fabric, different tactile perceptions. Inside

Figure 2: Results of the area detection algorithm (on the right side) and the RGB acquisition (on the left side).

the hollow cylinder, just beneath the fabric, a 3 Megapixel camera endowed with high-luminosity LEDs is mounted. During the tactual indentation, the fabric is strained and the fabric area which comes into contact with the finger changes according to the level of stretching and the applied force. The camera allows to acquire the image of the strained fabric and by means of suitable processing algorithms, the contact area can be estimated. In this way we can simulate many force-displacement characteristics, i.e different materials. At the same time the contact area on the fingerpad indenting the fabric can be also measured. The system was characterized in terms of force-displacement and force-area provided by the fabric under different levels of stretching. These levels were obtained changing the position of the crown, in a range between 0 (0 was chosen near the top of the cylinder) and 30 mm, with an incremental step of 3 mm. According to mechanical contact theory, the relationship between force and displacement on a material is related to the stiffness and can be approximately associated to the kinaesthetic information. We used a load-cell to measure the force applied on the fabric during the indentation. This force sensor was coupled to an LVDT position sensor, in order to measure the vertical displacement induced on the fabric. In this way we obtained a real-time measurement of the force-displacement characteristics for every position of the crown, using a linear interpolation.
Following other works of the authors [2, 3], here we keep sustain the conjecture that a large part of the cutaneous information is conveyed by the spread of the contact area over the fingerpad under an increasing load. A wood model of the human fingerpad was used to indent the fabric surface. The indentor was connected to the LVDT sensor. We acquired the image of the strained fabric, by means of the camera endowed with high-luminosity LEDs, placed just beneath the fabric (at a distance of 30 mm). Upon suitable processing algorithms, we were capable of estimating the contact area under the indenting force. In this way we obtained a real-time measurement of the force-area characteristics. When we would like to mimic a given material having a specific force-displacement then we have to identify which position of the motor provides the fabric elasticity whose force-displacement approximates that of the material. The force-area behaviour is strictly related to the elasticity of the fabric, hence, at least in this preliminary prototype, it cannot be independently controlled. The system is endowed with suitable graphical user interface in order to control the FYD and display the measurement of the variables involved in the contact. A simple virtual reality representation of the interaction between the fingertip and the fabric is also provided.

3 Results and Conclusions

Some preliminary episodic tests have been performed in order to validate performance of the display. Five blindfolded subjects were asked to rank, in terms of softness, five artificial specimens, presented in random order. We rendered these specimens with the display just moving the circular crown towards five different positions, corresponding to five different levels of stretching of the fabric. A preliminary assessment of performance is provided by a comparative evaluation with a display previously developed, the CASR [2]. In fig.3 results of ranking experiments from one subject, chosen by chance, on CASR and FYD displays, are reported on the left and right sides respectively, by way of illustration. As it can be seen, the percentage of correct answers with the FYD is 100%. Although these results are very preliminary and have no statistical significance, they are very promising and encouraging to investigate more in-depth about the performance of this display. The FYD provides higher performance than CASR, enabling subjects to better discriminate different levels of softness.An improved design of FYD is under way.
Next developments aim at both performing further tests, with a statistically significant number of subjects, also in order to evaluate the importance of the visual cues provided by the virtual reality representation, and implementing a trajectory tracking control system in order to reproduce desired force-displacement and force-area behaviours by exploiting data stream video coming from the camera installed on the device.

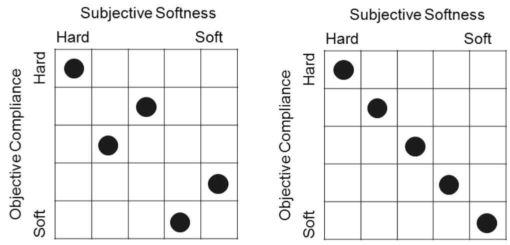

Figure 3: Confusion matrices showing how the objective compliance is subjectively perceived by one subject when the CASR display, on the left side, and the FYD, on the right side, are used to perform ranking experiments.

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