A fabric-based wearable haptic system for advanced human-machine interaction

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***Abstract*—In this work we report on a fabric-based wearable haptic system that can deliver both softness information and tangential sliding cues at the user's finger. This system has two unique characteristics: (1) it enables both active and passive haptic exploration; (2) thanks to the usage of a fabric as interaction surface, it can be successfully employed to superimpose tactile cues without impairing user's natural cutaneous perception, thus opening to interesting perspectives in the field of augmented reality. In this paper, we describe the main components and functioning principles of the device and discuss two successful applications in augmented reality and surgical robotics, respectively.**

***Index Terms*—wearable, haptics, softness, augmented reality**

I. Introduction

A natural step on the path towards an extended distribution of haptic devices is the development of a wide variety of wearable systems (WHSs). These devices can be easily worn by users, and allow a natural and efficient human robot interaction with virtual or remote objects. Regarding the latter case, it is worth mentioning that the usage of wearable haptics solutions ensure the intrinsic stability of the telerobotic loop relying on sensory substitution [1].

There is a high number of solutions to provide a wide variety of stimuli in literature. Within this rich family of new devices, softness-related stimuli are largely under-represented. Softness is one of the most accessible haptic properties, since its perception starts immediately after the first contact phase. With this motivation we started developing a WHS capable of conveying controllable softness cues, the W-FYD (Wearable-Fabric Yielding Display - see Fig. 1(a)) [2].

Our device is the first one capable of providing a controllable softness feedback on the user's finger-pad enabling both active and passive exploration mode, see Fig. 1. In addition to this, the W-FYD is also capable of providing tangential sliding cues at the user's finger-pad. This device is the wearable evolution of devices previously developed by the same research group [3], which controls the stretching level of a bi-elastic fabric to reproduce different stiffness levels.

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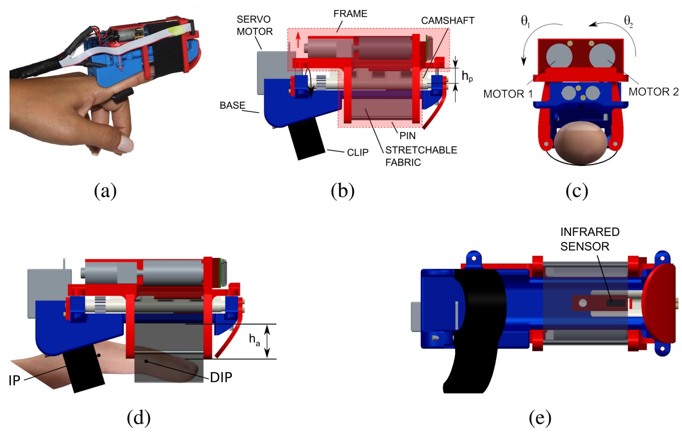

Fig. 1. W-FYD functioning principles [2]. (a) W-FYD Prototype worn on the user's finger. (b) Passive Mode: Lifting mechanism (in red the moving parts). (c) Motor angles definition. (d) Active Mode: Finger interaction and (e) position of the infrared sensor.

Thanks to the design of the W-FYD, based on device wearability and fabric deformability, it allows to superimpose tactile cues without obstructing the sensation derived from the direct contact with external items. This aspect is very useful to allow a full haptic experience in augmented reality (AR), allowing a true *tactile augmented reality*.

II. The W-FYD

The W-FYD uses a layer of isotropic elastic fabric (Superbiflex HN by Mektex S.P.A.) as interaction surface for the user. The device can be fixed on the user's finger through a suitably designed clip, ensuring stability. The device is composed of two main parts: the *base* and the *frame*. The base, directly fixed on the user's finger, hosts the lifting system actuated by a servo motor (HS-5055MG Servo by Hitec) that allows the passive interaction through two camshafts connected by gears. The frame, that is moved by the lifting mechanism, hosts the two DC motors (Pololu 298:1 Micro Metal Gearmotor) used to move and stretch the fabric band allowing the stiffness control. The part of the fabric band acting as contact interface with the user is kept flat by two pins rigidly fixed to the frame. A pin helps in maintaining the two parts aligned during the activation of the lifting mechanism and an elastic band allows the system to go back to the original state at every iteration.

As previously specified, the device can enable two different modes of interaction: a passive mode, in which the user is stimulated via the lifting mechanism pressing the contact interface against the finger-pad (the finger is not moving - see Fig. 1(b)); and an active one, in which the finger actively probes the interaction surface for softness. In the passive mode only tactile cues are provided to the skin [4]. In the active mode, being the device attached to the back of the finger, the only finger movement the user can perform is the flexion of the distal phalanx, to indent the fabric, as shown in Fig. 1(d).

Thanks to its structure that actuates the fabric and the lifting system in a separate manner, the W-FYD allows to decouple the force exerted by the user on the fabric from the fabric stiffness control, differently from previous literature.

The change in the stretching level of the fabric is obtained controlling the angle of the two DC motors, causing different levels of stiffness to be provided on the user's finger-pad. In the active mode, the stiffness is managed considering the indentation generated by the user h_a and measured with an infra-red sensor (Avago HSDL-9100 analog distance sensor) attached to the base (Fig. 1(e)). Meanwhile, in the passive mode, the indentation h_p is directly generated by the system and the stretching state of the fabric is controlled accordingly.

If the two DC motors are controlled to rotate in the same direction, a sliding movement of the fabric is generated on the user's finger-pad.

A custom-made electronic board (PSoC-based electronic board with RS485 communication protocol[1]) controls motor positions - based on the readings of the encoders (16 bit magnetic encoder AS5045 by Austria Microsystems) - and the servo motor, and enables to acquire the measurements from the IR sensor. The entire cycle works at a frequency of 200 Hz.

For a correct use of the W-FYD, a characterization of its stiffness work-space, in terms of force and indentation, similar to what we did in [3], was performed.

III. Applications

Between all the possible applications of the device, we integrated it in two different experimental setups: tactile augmented reality and softness feedback.

A. Tactile Augmented Reality in Open Surgery Training

In [5] the W-FYD was used in a slightly modified version to simulate the pulse of an artery in a passive phantom used for surgical training, following the paradigm of tactile augmented reality.

The W-FYD was integrated within the AR-Sym, an augmented physical simulator to train on some important steps of the cholecystectomy procedure. The existing platform is composed of a realistic physical replica of the involved anatomical structures, an electromagnetic tracking system and an optical calibration-acquisition system and a visual augmented reality system to help the trainee recognizing the different parts. In this work, the use of the W-FYD as tactile augmented reality system allows to integrate the visual cue with tactile cues: the user can not only see the position of the cystic artery through the AR scene, but can also feel its pulse.

To implement this effect, the lifting mechanism was used to generate an artery-like pulse waveform when a series of conditions were satisfied: contact with the physical model in correspondence of the artery, and contact pressure within the physiological range for artery pulsation. Furthermore, the amplitude of the pulse was managed depending on the pressure exerted and measured on the artificial organ.

The system was tested with 10 surgeons, who evaluated positively the application.

B. Softness Rendering in Robot-assisted Surgical Interfaces

In [6], a completely different implementation of the system was tested. In this work, the W-FYD was used to provide the user with a real-time softness feedback during a simulated robotic-assisted surgery procedure, a conservative myomectomy, to allow myoma palpation.

The system was composed of a master-slave architecture. The master was a commercial haptic device capable of providing kinaestetic feedback (Geomagic Touch - 3D System, USA), while the slave was a structure composed of a frame and an indenter provided with a force sensor. In this system, the W-FYD was applied to the stylus of the Geomagic Touch, to provide to the user the softness feedback, rendering the one computed from the acquired force and indentation information from the specimens indented by the slave robot. The vertical motion of the indenter was controlled through the vertical movement of the master. To avoid stability problems, the Geomatic Touch was used only as input device, while the tactile feedback was delivered through the W-FYD in passive mode, allowing the loop to be intrinsically stable.

Preliminary experiments showed that the W-FYD allowed to perceive the presence of the irregularities inside the sample under exploration. Based on this, we believe that the integration of the W-FYD with a surgical robot can allow more precise perception of myomas during intraoperative procedures, enabling a less invasive and more located surgical intervention.

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