A data-glove with vibro-tactile stimulators for virtual social interaction and rehabilitation

Silvia Pabon, Edoardo Sotgiu, Rosario Leonardi, Cristina Brancolini, Otniel Portillo-Rodriguez, Antonio Frisoli, Massimo Bergamasco

{ e.sotgiu@sssup.it, s.pabon@sssup.it, a.frisoli@sssup.it, m.bergamasco@sssup.it }

Abstract

A data-glove is presented in this paper as an alternative to more expensive devices to be used in different science areas. This glove is characterized by low cost and a rugged construction. A further advantage is that consists of purely goniometric sensors, so they are not sensitive to the size of the user's hand; for this reason it does not require of calibration before its use. The integration of vibro-mechanical stimulators with the hand motion capture makes this data-glove very useful in many contexts such as telerobotics, rehabilitation and virtual social interaction.

Keywords--- **Glove, goniometric sensor, vibro-tactile feedback**.

1. Introduction

1.1 State of the art

Vibro-tactile feedback cues can significantly enhance touch perception for virtual environment applications with minimal design complexity and cost [1]. From a developmental psychological perspective, touch plays an essential role in our perceptual construction of spatial environmental layout. Combining touch and vision allows the simultaneous extraction of perceptive process invariants, crucial for establishing the reciprocal connections that allow for higher order perception and categorization of objects and environments [2].

There are several types of data-glove commercially available [3], [4], [5], but not so many researchers [6] or [7] have integrated these glove with prototypical vibro-tactile pads. All of these serve the purpose for which they were originally intended (e.g. data input, object manipulation, computer game accessories), but they are either too delicate or too expensive or very difficult to calibrate.

People have different length, thickness of their fingers and size of their hands' palm, so it is necessary a calibration / normalization procedure to match the sensor output spans with the specific user range of motion. For the most of commercial Data-gloves previously cited, quantitative assessment of rigid range of motion (RoM) is required and a measuring procedure must be done ([8] and [9]).

A vibro-tactile data-glove (PERCRO data-glove) characterized by a low cost, robust construction and no need previous calibration is proposed in this paper. PERCRO data-glove (Figure 1) is based on absolute goniometric sensors [10], and this prototype has been designed and developed as a device to perform the natural and every day human gesture activities (grasping simple objects, touching surface,…), useful to fulfil psychophysics experiments and rehabilitation procedures.

Figure 1: The Percro data-glove.

The main objective was to develop a data-glove allowing multiple angular finger joint positions to be recorded in dynamic manipulative task and applying vibro-tactile cues to simulate the contact with virtual objects.

In the next section, a description of the goniometric sensor and its characterization will be shown. In the third section, the vibro-tactile actuators will be described. In the fourth section, a brief description of the hardware architecture will be shown and then in the fifth section a description of the integration with a software platform for virtual environment will be presented. Finally, in the last section the conclusions and the future works will be reported.

2. System Hardware Overview

The PERCRO data-glove is equipped with at least two sensors of different length for each finger. They measure the angular displacement of proximal (MCP) and medial phalanxes (PIP) with respect to the back of the hand (Figure 2). The difference between the two signals is implemented via software in order to obtain the relative angular displacement between the two phalanxes. The flexo-extension of the distal phalanx with respect to the medial is considered equal to the medial with respect to the proximal; therefore just two sensors are enough to describe the flexo-extension of each finger. The adduction-abduction movement of each MCP finger is not measured, because it has not to be needed to perform the main gestures useful for the foreseen applications. A third sensor has been added to the thumb: it bends in a plane normal to the flexo-extension of the other two sensors.

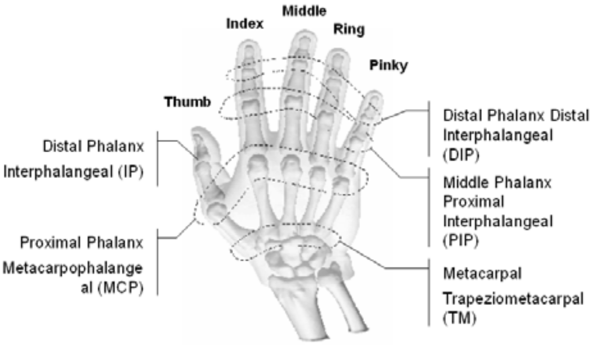

Figure 2: Representation of the human hand joints.

The vibro-tactile actuators are displaced on the back of each fingertip to stimulate the human skin receptors when the virtual hand comes in contact with a virtual object.

2.1. Goniometric sensor

The goniometric sensor is composed of only four parts: a commercial cylindrical permanent magnet, a commercial miniaturized Hall Effect sensor with a built-in signal amplifier, a multi wire flexible steel cable; a flexible thin beam made of plastic with a square cross section a longitudinal hole. The beam ends with a casing for the magnet and the Hall effect sensor [10].

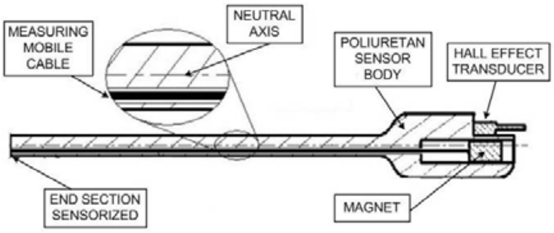

Figure 3: The main part of the goniometric sensor.

The sensor (Figure 3) is composed of a transducing bulb and a sensing flexing bar, with respective dimensions of (5 x 8 x 21) mm and (2.4 x 2.4 x *L*) mm where *L* is a variable length.

The working principle of the sensor relies on the fact that a flexible beam with the deformed elastic line lying on a plane has the following property: the longitudinal elongation of its fibers depends linearly on their curvature and their distance from the neutral axis of the beam.

When a relative bending angle $d\theta$ is imposed to a beam element of length *dl* (Figure 4), the length of the neutral fiber of the beam remains unchanged while the fiber, positioned at a distance ε from the neutral axis, changes its length by a quantity of:

$$dL = \varepsilon \cdot d\theta$$

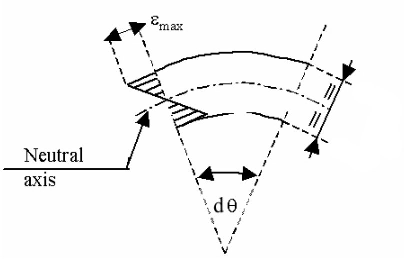

Figure 4: The working principle.

Integrating this variation along the entire beam, in case of constant ε, we obtain:

$$L = \int_0^L dL = \varepsilon \int_0^{\Delta\vartheta} d\vartheta = \varepsilon \cdot \Delta\vartheta$$

Therefore, the total elongation of the fiber is a function of the angle between the two endpoints of the flexible beam and it is independent from its specific elastic line.

In particular, a free moving axially rigid wire inside a eccentric hole but parallel to the neutral axis, having its end fixed to one endpoint of the beam, will produce a linear displacement of the other end of the wire proportionally to the rotational displacement. This quantity can be transduced with a low-cost linear Hall effect sensor that measures the intensity of a magnetic field produced by a magnet attached to the movable end of the wire.

Each goniometric sensor needs a calibration phase (Figure 5) to obtain the slope coefficient of the theoretical characteristic tension- angle of the sensor, *K*,

$$\Delta\vartheta = K \cdot \Delta V + \vartheta_0$$

where ϑ_0 is the angle measured when V = 2.5 volts.

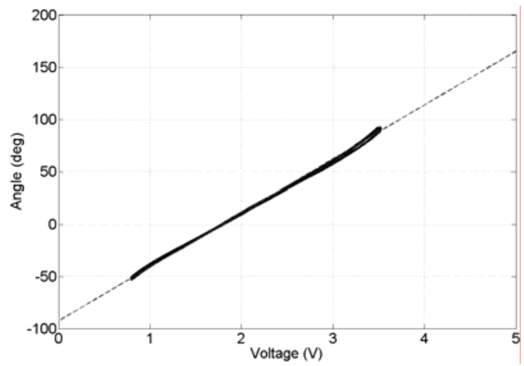

Figure 5: Tension-angle characteristic.

The resulting performances of the sensor are the following:

- Range of measure: (0-180) degrees;
- Accuracy: 2 degrees;
- Output span: 0-5V.

The advantages of the sensor are:

- adaptability to any external kinematics, due to its flexible body;
- low production costs because based on few commercial low-cost components
- low non-linearity error (2-5%) of the angle-voltage relation;
- minimum hysteresis (1-3%), due to the backlash between the hole and the steel cable;
- sensor calibration is "for life".

2.2. Vibro-tactile actuators

Neural mechanisms that are involved in the sensation of touch have been studied extensively from many years ago. These studies have demonstrated the sensory capacity of a human by functional proprieties of the sense organs in the skin, rather by mechanisms within the central nervous system [11].

The are four different tactile units in the skin area of the human hand: two rapidly adapting, (RA) Meissner corpuscles and Pacinian corpuscles, and two slowly adapting (SA) Merkel cells. The slowly adapting are sensitive to low frequency stimulation (<10Hz) and primarily encode pressure, texture and form of the object. The Meissner corpuscles are most sensitive to vibro-tactile frequencies of 30 Hz and response to the flutter, slip, and motion of objects. The Pacinian corpuscles are most sensitive to high frequency vibration centered around 200 Hz.

In order to stimulate the Pacinian corpuscles vibrating motors have been attached on the palm-side of each fingertip. These actuators consist of small motors commonly used as vibration alarms in pagers, mobile phones and many vibro-tactile game controllers (Figure 6), which can be made to rotate at different speeds, and so different frequencies. Vibration intensity is controlled varying the voltage sent to the motors.

The voltage constant of such actuators is K_E = 0.0015 Vs/rad, so at the maximum voltage, with an eccentric mass (0.16gr) mounted on the motor's shaft, the frequency is about 500Hz.

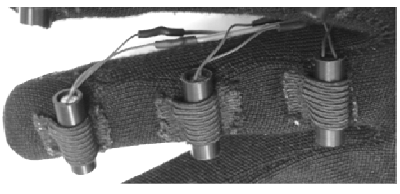

Figure 6: Vibro-mechanical actuators on the finger.

2.3. Low level control architecture

The hardware control architecture (Figure 7) acquires the analog signals from the goniometric sensors, and converts them to digital signals, then sends the digital data to a host computer through a serial communication protocol.

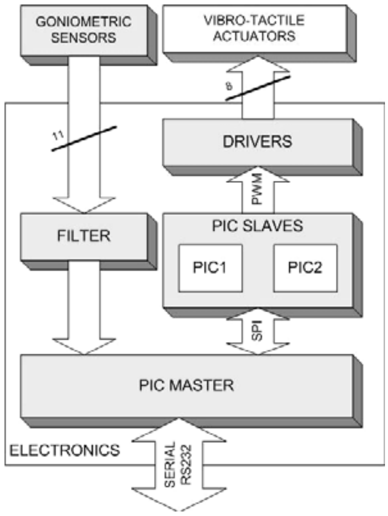

Figure 7: Data-glove electronics architecture.

Three microcontrollers (µCs) have been used to develop a master-slave mini-network. One µC (PIC18LF4420) acts as a Master and two µCs PIC18LF443 act as slaves. The Master µC is used to read the signals from the 11 goniometric sensors using its internal ADC of 12 bits. The communication between the Master µC and the host computer is performed through serial communication. The Master µC receives from the pc host the enabling signal and the voltage intensity command for each Slave µC.

The communication among the Master and Slaves µCs is based on the Serial Peripheral Interface (SPI) that guarantees a transfer rate of 12MBit/s. Each slave can control four motors with different PWM signals using a Darlington array ULN2803 which provides the necessary current and protection for the actuators.

3. Graphic application

In order to perform a realistic visual stimulus to the user a virtual environment (VE) with an avatar of the user's hand has been implemented.

This environment is a dinning table scenario (Figure 8) consisting of virtual plates and kitchen tools. The main task is to move and pick-up the objects around a table and feels the tactile sensation made by each hand-object contact.

The graphic representation of the hand and the kitchen environment (Figure 8) was developed using a virtual 3D platform called XVR [12] [13], which is an advanced and lightweight system for the development of VR applications both for the Web and for 3D immersive systems.

To allow the user sweep the VE, a 6DoF magnetic tracker (Polhemus) has been attached to the data-glove. Such tracker permits to acquire the position and the orientation of the user's hand respect to a physical receiver.

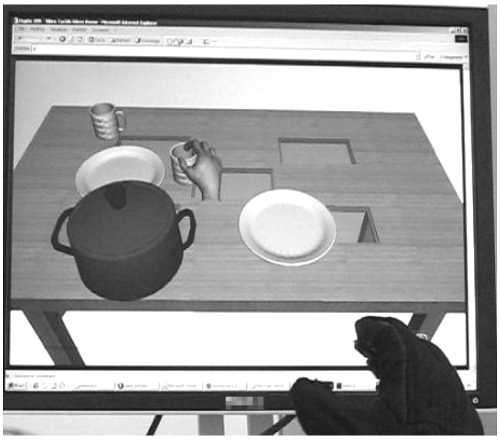

Figure 8: Virtual kitchen environment.

For this application, the angular positions of the skeletal joints are associated to the obtained angles, and then 3D hand meshes are deformed applying geometrical transformations to the point of the mesh associated to the corresponding point of the dynamics hand (Figure 9).

In order to render a realistic manipulation of the kitchen objects, it was necessary integrate the VE with PhysX AGEIA dynamics library [14] to calculate the collisions between the virtual hand fingers against the virtual objects.

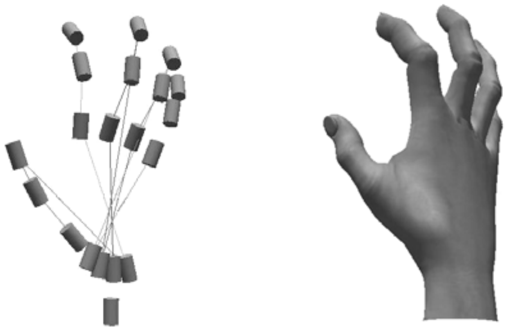

Figure 9: Dynamics hand and virtual meshed hand.

Conclusions

In this paper a data-glove developed for the study of tactile stimulation and social mediated interaction by touch it has been presented. To carry out the mentioned goals it will be necessary modulate the surface characteristics of the motor-glove contact and study the influence of the perceived tactile sensations [15]. We could generate sensations for different stiffness, using different waveforms in the vibro-tactile pads. The technologies showed in this paper will be also adapted and used in rehabilitation and training of cognitively disabled persons.

A different version of light tactors based on an electroactive polymers is also currently under development, capable of producing a static indentation at the contact area.

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