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Design of a tactile display to support materials perception in virtual environments

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ABSTRACT

Materials properties simulation by means of haptic devices is one of the most significant issues in the design of new human-computer interfaces to support virtual prototypes interaction in numerous product design activities. Notwithstanding the several research attempts, a very natural perception of materials has not been achieved yet. We present a novel tactile display. It combines both mechanical and electrotactile approaches to simulate natural tactile sensations. In order to enhance experience acoustic and visual cues are integrated. A signal generation method allows correlating materials properties and simulating signals according to the characteristics of fingertip mechanoreceptors. The final scope is making users perceive the object's surface roughness, slickness and texture coarseness. Research results are the developed simulation method and the detailed design of the whole tactile display. The preliminary prototype is under construction.

KEYWORDS: Haptics, 3D interaction, multimodal interaction

INDEX TERMS: D 2.6 [Interactive environments] – H 1.2 [Human Factors] – H 5.2 [User Interfaces] – I 2.10 [Modeling and recovery of physical attributes]

1 INTRODUCTION

The main challenge in aesthetic product design concerns the creation of a valuable product experience and the transfer of meanings to final users. Virtual prototypes (VP) are often used to support the different design stages and reduce time to market. Limitations are low realisms of product experience, lack of a real time interaction, low usability, poor touch feedback.

Haptic devices aim at reproducing the sense of touch by stimulating kinesthetic [1,2] and cutaneous feedback [3-5]. Cutaneous feedback in particular is fundamental to have realistic simulation and to effectively perform design activities (e.g. product validation, material selection, shape exploration, etc.) [2,6]. However, mature solutions in tactile simulation for design applications have not been reached yet.

In this context, we have designed a novel tactile display able to reproduce tactile sensations given by materials properties during the exploration of VP surface. It represents an innovation compared to current systems for the following aspects: a) the correlation between the surface finishing properties and the signals' waveforms generated from processing of real material samples; b) the reconstruction of stimulating signals considering the frequency ranges of human tactile receptors; c) the integration with other VR-based technologies for product visualization and sound simulation to create a multisensory experience and enhance the tactile perception of materials.

2 METHOD FOR MATERIALS SIMULATION

To develop haptic material simulation, a feedback system is required to translate material properties into real-time tactile display. To this aim we adopted a selective stimulation method that combines electrotactile and mechanical approaches [7]. In this way electrical signals transmitted by the tactile surface and a mechanical vibration generated by a shaker are associated.

The main steps of the proposed methodology are:

1. Investigation of real material samples by means of an optical scanning system to gather useful data about surface finishing profiles and properties;
2. Data processing according to human receptors characteristics (sensitive frequency range, receptive field, etc.) to obtain a set of representative signals which can be converted into electrotactile and mechanical stimuli;
3. Signal synthesis for each material class and generation of an electro-mechanical stimulation by combining all contributes;
4. Design of the tactile device;
5. Tactile display prototyping and signals implementation.

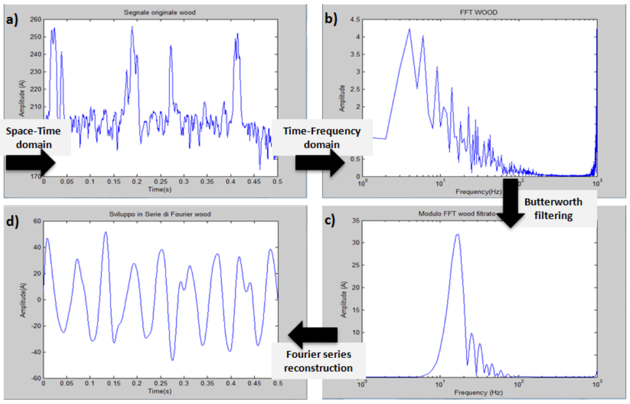

Figure 1. Processing steps to reconstruct material surface profiles

Step 1 concerns the optical scanning of five materials samples generally used in consumer goods (metal, paperboard, soft rubber, textile, wood). We adopted CHRocodile E by Precitec as a scanning system. Step 2 refers to the elaboration of the digitalized surface data to define a set of simulating signals (Fig.1). Digitized data have been converted into significant spatial profiles. Then, they have been translated from space to time domain and after to frequency domain to recognize the spectral components. In more details, the original profiles have been processed by Fast Fourier Transform (FFT) and filtered to cut off the high frequency components by means of a Butterworth filter. Finally, the most significant frequencies have been extracted for each material sample and used to reconstruct a simplified electric signal as a Fourier series. Furthermore, the analysis of the high frequency components of the material profiles elaboration allows selecting the vibratory frequency of the mechanical stimulation,. It varies in a specific range depending on the target mechanoreceptors. Procedure implementation has been carried out in Matlab and LabView. Step 3 concerns the generation of a proper set of stimuli able to virtually simulate material properties through different signals. According to the selective stimulation method, material data have been elaborated and two different stimuli generated: 1) an electric signal as Fourier series, which directly derives from the processing procedure and is able to elicit both the fast and the slow adapted units of the skin (FAI and SAI); 2), a mechanical vibration in a frequency range of 200-250 Hz able to excite the second type of fast-adapted receptors (FAII). Step 4 regards with the adoption of a systematic approach to design the tactile device while Step 5 is meaningful for the validation of the conceived system and of the proposed methodology.

3 SYSTEM OVERVIEW

In order to design and develop the tactile display, we have adopted a systematic approach and followed the functional architecture defined in a previous research work [1]. The system consists of six functional modules (Fig.2):

1. a graphic module that creates the visual representation;
2. an acoustic module that adds acoustic cues to drive subjects moving in the workspace and enhance contact sensations;
3. a thermal module that adds heat sensations;
4. a control SW module that manages I/O signals from/to the different identified units (i.e. graphic, acoustic and thermal);
5. a tracking module, consisting of a wearable tracking system to capture and record hand and fingers motion;
6. a tactile module which represents the core of the whole system and reproduces materials properties as defined by the simulation methodology. It consists of two sub-units: 1) Surface Texture Modelling unit (STM module) representing the HW part of the tactile module, 2) Tactile SW, which generates signals controlling the STM module.

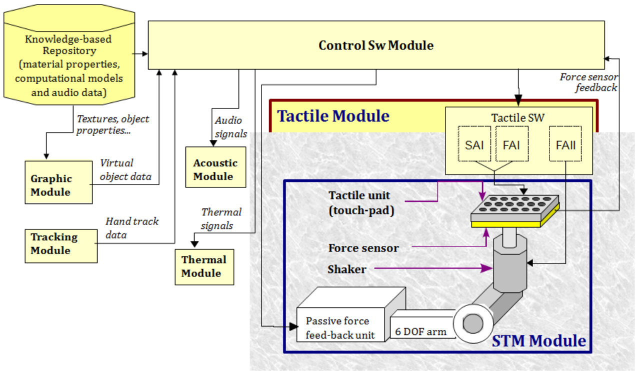

Figure 2. System architecture and main functional modules

The HW touch-pad (Fig.3, a) consists of 64 pin-electrodes arranged as a squared grid, in order to spatially distribute current flow. The diameter of the pin-electrodes is set at 1.0 mm while the distance between the centers at 2.0 mm. The electrodes are employed as points of stimulation. Electric current flows from a pin electrode to the surrounding ones, stimulating mechanoreceptors according to a configuration set in advance through the tactile SW. A scalable multiprocessor platform is used to pilot the STM module consisting of one master and some slaves. At each instant of time, the tactile SW defines the state of each electrode: each of them can be in different states (insulated, signal, ground) depending on switch commutation. Furthermore, two low profile force sensors (FSS-SMT Series of Honeywell) are positioned under the touch-pad to acquire the fingertip pressure.

The tactile SW (Fig.3, b) consists of a multi-package SW tool based on a customized application running on Virtools 4.0. It provides direct outputs such as: a video flow to the see-through glasses used for visualizing the virtual prototype, data retrieved from the optical tracking system for the Labview application, audio data from the database and sound signals to the headphones. It also represents the managing platform of the I/O information processed by the different SW packages:

- CATIA V5 (by Dassault Sistemès) as 3D CAD tool,
- 3DSMax 8.0 (by Autodesk) as graphic rendering tool,
- ARToolKit Plus plug-in for Virtools as the software library to build Augmented Reality (AR) applications,
- Tracking tools 2.0 plug-in for Virtools, as the Optitrack control software;
- a customized application in Labview to automate a complex set of functionalities (i.e. initializing the different tactile signals; calibrating the signals amplitudes; directing data packages to the master-slave platform; run-time adjusting the signals amplitude; regulating tactile data packages by considering the finger position, etc.).

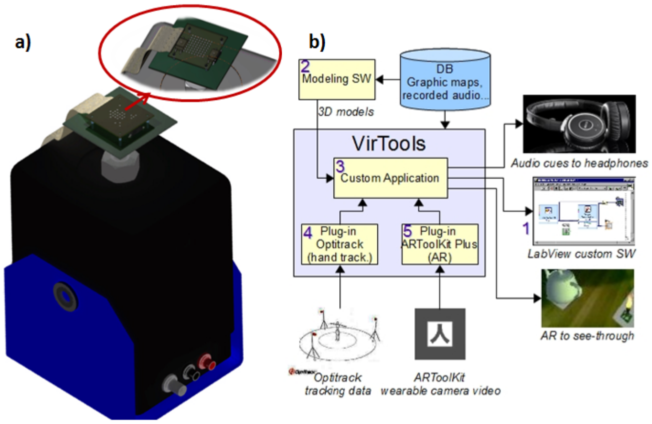

Figure 3. Touch-pad HW (a) and Tactile SW architecture (b)

4 CONCLUSION

The research work presents a novel tactile display to support materials properties perception during VP surface exploration. By adopting a selective stimulation method, the system combines electrotactile and mechanical vibration approaches to simulate softness, texture coarseness and roughness properties. The main innovation concerns the close correlation between real surface properties, human mechanoreceptors and stimulating signals. Actually the tactile system is a preliminary prototype and the integration of all system modules has not been carried out yet. The early testing activities will be able to validate the adopted solutions.

REFERENCES

[1] M. Solazzi, A. Frisoli and M. Bergamasco. Design of a Novel Finger Haptic Interface for Contact and Orientation Display. *Proc. IEEE Haptics Symposium* (Waltham, Massachusetts, USA, March 25-26, 2010), pages 129-132.

[2] M. Bordegoni and U. Cugini. Designer-Centered Haptic Interfaces for Shape Modelling. In HCI, volume 14, pages 441-445. 2007.

[3] S. Okamoto, M. Konyo, T. Maeno and S. Tadokoro. Roughness feeling telepresence system on the basis of real-time estimation of surface wavelengths. *Proc. IEEE/RSJ* (San Diego, California, USA, October 29 – November 2), 2007.

[4] L. Winfield, J. Glassmire, J.E. Colgate and M. Peshkin. T-PaD: Tactile Pattern Display through Variable Friction Reduction. *Proc. EuroHaptics Conference*, pp. 421-426. 2007.

[5] H. Kajimoto, N. Kawakami, S. Tachi and M. Inami. SmartTouch: Electric Skin to Touch the Untouchable. In *IEEE Computer Graphics and Applications*, vol. 24 (1), pp. 36-43. 2004.

[6] M. Mengoni, B. Colaiocco, M. Germani and M. Peruzzini. Design of a novel Human-Computer Interface to support HCD application, *Proc. ASME IDECT-CIE Conference* (Montreal, Quebec, Canada, August 15-17, 2010M.

[7] Konyo, S. Tadokoro, A. Yoshida and N. Saiwaki. A tactile synthesis method using multiple frequency vibrations for representing virtual touch. *Proc. IROS 2005* (Alberta, Canada, August 2-6), pp. 3965-3971. 2005.