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A Real-time Synthesizer of Naturalistic Congruent Audio-Haptic Textures

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Abstract. This demo paper presents a multi-modal device able to generate real-time audio-haptic signal as response to the users' motion and produce naturalistic sensation. The device consists in a touch screen with haptic feedback based on ultrasonic friction modulation and a sound synthesizer. The device will help investigate audio-haptic interaction. In particular the system is built to allow for an exploration of different strategy of mapping audio and haptic signal to explore the limits of congruence. Such interactions could be the key to more informative and user-friendly touchscreens for Human-Machine-Interfaces.

1 Introduction

The mental representation of the environment is shaped by a multitude of sensory inputs integrated across space, time and sensory modalities. The perception of a same signal is reinforced by being congruently detected via multiple modalities such as touch, audition and vision. In this context, several studies showed that the cross-modal integration of haptic and visual feedback is achieved in an optimal way following a maximum likelihood principle [1]. However, audio-haptic interactions are less understood. In some instance, audition influences touch while exploring a texture. For instance, the *Parchment-skin Illusion* describes an modification of the tactile perception of roughness due to an attenuation of the high-frequencies of the sound produced by the interaction with solid objects [2]. This effect has been rigorously demonstrated on abrasive papers [3]. The judgement of tactile roughness is also altered when listening to synthetic sounds instead of recorded, touch-produced sounds [4]. For the effect to reach his full potential auditory and tactile stimuli must be congruent both in intensity [5] and spatially [6]. Audio and haptic feedback have already been associated to guide the user gesture on an interface [7] [8], but the expected performance improvement by combining this modalities is not evident. Investigating correlations between texture parameters and sound [9], it was demonstrated that

texture roughness is better perceptively match to the sound intensity than to the pitch.

This paper describes a device able to produce congruent audio-haptic signals in real-time as a function of the user motion, using a combination of a surface-haptic device and a sound synthesizer. Investigations of the audio-haptic interactions by simulating a wide range of tactile stimuli and realistic sounds are possible. Better understanding of cross-modal audio-haptic interactions could be the key to more informative and user-friendly touchscreens for Human-Machine-Interfaces.

2 Apparatus

2.1 Audio synthesizer of interaction sounds

The sound synthesizer is based on perceptually relevant sound morphologies associated with the recognition of objects (structural invariants) and actions (transformational invariants) in line with the ecological approach to perception proposed by Gibson [10]. The identification of invariant sound structures led to an *Action-Object Paradigm* for sound synthesis in which sounds are described as the consequence of an action (like knocking, rubbing or scratching) on an object, defined by its shape (width, thickness, curvature...), and material (metal, wood, glass, ...). The action is modeled by a low-pass filtered noise simulating successive impacts and the object by a resonator, implemented through a resonant filter bank. A perceptual mapping enables continuous transitions between the different categories of actions and objects [11].

2.2 Ultrasonic friction modulation technology description

The haptic surface device uses ultrasonic levitation to modulate the friction between a glass plate and the user's finger. The glass plate vibrates at a resonant mode 35 kHz over amplitude of 3 microns. These vibrations are not directly perceptible by the skin, but they cause the finger to slightly levitate from the plate and dramatically reduces the friction between the finger and the screen [12]. Modulating the amplitude of the ultrasonic vibration allows for a controlled modulation of the friction force applied to the finger. Patterning friction as a function of position and velocity of the finger can thereby create the illusion of touching shapes and textures [13].

2.3 System architecture

The global operation of the audio-haptic synthesizer is described in Fig. 1. Haptic rendering is achieved by a simple texture generator. The texture is encoded by three parameters : a sine wave described with fixed spatial frequency f_s and amplitude, A and an entropy value h referring to the proportion of noise. The resulting 1D friction map μ_{map} is thus calculated on the micro-controller and updated each time the parameters f_s , A , h are modified on the user interface. μ_{map}

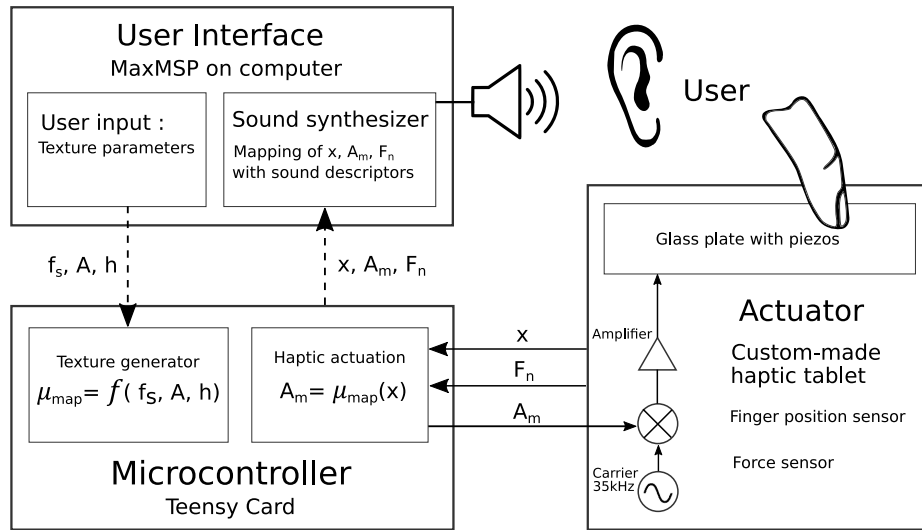


Fig. 1: Description of the audio-haptic synthesizer operation. Analog communications are printed in continuous lines and digital communications in dashed lines.

describes the friction level according to the finger position x . While running, the haptic signal generation is performed by a real-time loop that first acquires the user's position x and outputs the modulation amplitude A_m stored in the friction map. A_m is then converted into an analog signal modulating a high frequency carrier wave, and therefore the frictional behavior of the plate. Simultaneously, the finger position x , the modulation amplitude A_m and the normal force applied by the finger on the plate F_n are sent by the microcontroller to the Max/MSP sound synthesizer through a serial port. These parameters are used to control the sound synthesizer in real-time.

3 Audio-haptics signal mappings

A prerequisite for the study on audio-haptic interaction is to recreate sounds that are perceived as congruent with the explored haptic texture. In this perspective, we investigated different mapping strategies between the haptic device and the synthesized sound. Previous studies [14] have shown that a finger movement on a surface can be simulated by mapping the finger velocity to the cut-off frequency of a low-pass filter. In this study we propose to proceed in the same way by varying the attributes of a band pass filter (f_0 , B and G) according to the contact properties of the haptic surface ($v = dx/dt$, F_n and A_m). We tried several possible mappings, but opted for the one in Fig. 2 through non-formal tests. We chose to apply this filter on white noise in order to demonstrate the

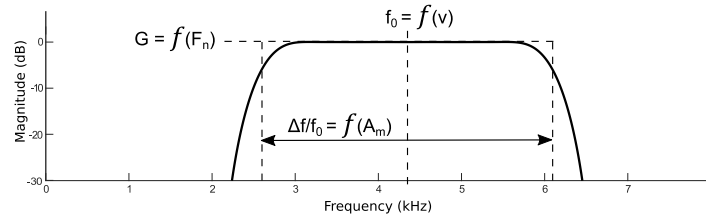


Fig. 2: Mapping between properties of the haptic surface and the bandpass filter attributes. The central frequency f_0 , the relative bandwidth $\Delta f/f_0$ and the gain G depend respectively to the finger velocity $v = dx/dt$, the current friction level A_m and the normal force applied by the finger F_n .

audio-haptic congruence on a neutral sound before generalizing this principle to more complex sounds textures.

The finger velocity, calculated as the time derivative of the position, is mapped to the central frequency f_0 of the bandpass filter. This central frequency increases linearly as the finger speeds up. Moreover, the current friction level A_m determines the relative bandwidth $\Delta f/f_0$. They are inversely proportional according to a logarithmic profile. Indeed, a high value of A_m corresponds to a minimum bandwidth. On the other hand, the normal force F_n exerted by the finger on the glass plate is collected to determine the gain G of the filter in a linear way.

From a perceptual point of view, with this synthesis method, sliding the finger with a higher velocity results in a brighter sound. Moreover, while sliding the finger on the ultrasonic surface, we perceive the rendered haptic effect as a periodic succession of low and high friction areas, with their intensity, frequency and regularity depending on the parameters chosen by the user. With the proposed mapping, slippery regions of the surface area are associated to a sound with a richer frequency content than the sticky area. It results in hearing pulses when the finger crosses these regions. Besides, an increase of the normal force applied by the user leads to a higher sound intensity.

We noticed through non-formal tests that an additional mapping, in which the velocity also influences the relative bandwidth, is also perceptually interesting and strengthens the congruence between the sound and the finger movement.

4 Conclusion

In this study, we aim to evaluate audio-haptic perception by combining an ultrasonic friction modulation device with a sound synthesizer that simulates environmental sounds. Both signals are simultaneously generated in real time and the parameters from the haptic device directly control the properties of the bandpass filter applied to the synthesized sound. During the demo session several mapping strategies and sound textures will be proposed and discussed in the light of previous and future perceptual evaluations of the device.

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