Sketch a Scratch

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Abstract
We present a tool for the multisensory sketching and exploration of surface or sound textures, by scraping, rubbing, or rolling. Such actions are governed by physical laws and give rise to a wide range of dynamic phenomena.

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Audio-haptic interaction, textures

ACM Classification Keywords
H.5.5 [Sound and Music Computing]: Modeling.

Introduction
Surface textures are most often experienced with touch, although their visual appearance and acoustic response to contact contribute to their multisensory perception [3]. In this work in progress we present a tool for the multisensory sketching and exploration of textures, for the purposes of designing surface qualities, experiencing them, as well as for transforming these actions into performative acts. Not only the exploration can involve probe-mediated touch, vision, and audition, it is also the acquisition of surface textures that can involve various sources, from still images to drawing, from audio recordings to vibration sensing.

A surface can be harsh, or smooth, and it can be rubbed with a fingertip, scraped with a nail, or rolled-over with a ball. Similarly, our voice can be harsh, or smooth, and utterances can be produced by bursts of turbulent air between the teeth, or by rolling our tongue. In the proposed tool, textures can be produced out of images, scanned along a line, or out of physical textures, scanned with a probe, or out of vocal imitations. The latter modality is called vocal sketching and has the same immediacy and effectiveness of hand drawing in visual sketching.

Prior Art

The Sounding Object project developed sound synthesis models based on contact phenomena occurring at the interface between an object and a surface. Friction is one such phenomenon based on stick-slip commutation. Other salient phenomena such as rolling are based on patterns of impacts. In those studies and models, surfaces were specified by some kind of noise model, possibly of fractal nature and including modulations of some kind [6]. The Sound Design Toolkit [2] was proposed as a set of physics-based sound models, organized according to an ecological taxonomy of everyday sounds.

Conan et al. [1] designed a flexible sound synthesizer for scratching/rubbing/rolling sounds. Sound generation is based on a dynamic impact model, and the impacts are distributed in time and controlled in amplitude according to stochastic models of scratching, rubbing, and rolling.

McDonald and Kuchenbecker [4] proposed a haptic simulation model for tool-mediated texture interaction, that is surface texture exploration mediated by a handheld probe provided with sensors. Their measurements show how lateral and axial accelerations at the probe are trains of complex pulses, each corresponding to a contact between the tip of the tool and a ridge in the texture grating. In their model, a dynamic model is used for impacts, and forces are transferred from the normal to the transversal plane via friction.

Merrill et al. [5] proposed using physical textures as affordances for brushing, scraping, striking, etc. that could be exploited for continuous playback and modification of prerecorded audio samples.

Textures

Two-dimensional textures can be observed visually and acquired as pictures, or they can be experienced with touch through scanning processes. Exploration with the bare finger gives a spatial, intensive measure of roughness. Exploration with a rigid probe (indirect touch) produces what is essentially a multidimensional signal in one variable: time. This signal carries information about surface roughness, hardness, and friction. Indirect touch often produces an audible signal that carries the same kind of information through sound [3]. On the other hand, any sound signal can be interpreted as a surface profile that could be appreciated with the other senses.

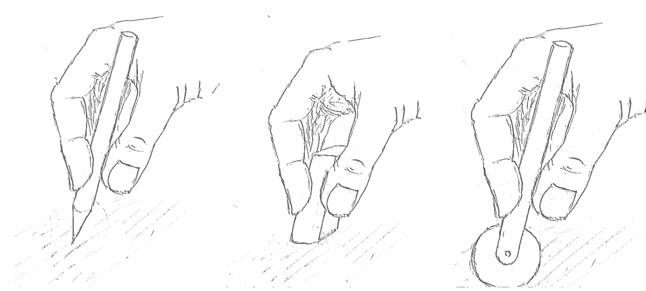

Figure 1: Scraping, rubbing, and rolling

In the proposed tool it is possible to specify textures in one or two dimensions with different means, and to move seamlessly from vision to touch to audition:

image $\rightarrow$ **vibration** An image is scanned along a line, and luminance values are converted into a one-variable surface roughness profile. This can be explored by scraping, rubbing, or rolling (Fig. 1), and the instantaneous force and displacement of vibrating surfaces can be rendered by means of a haptic device (respectively force feedback and vibrotactile actuators). Image filtering may be used to highlight the ridges;

image $\rightarrow$ **sound** An image is scanned along a line and luminance values are converted into a one-variable surface roughness profile. This can be explored by scraping, rubbing, or rolling, thus producing distinctive sounds;

vibration $\rightarrow$ **sound** A physical texture can be scanned using a probe, and an accelerometer or a piezo sensor can be used to capture the resulting vibrations;

sound $\rightarrow$ **vibration** Any sound, especially if inherently textural, can be used as a surface profile to be experienced through touch. The sound may itself contain information about the kind of exploration (e.g., scraping) of such texture. For the specification of textures in the audio domain there are some notable possibilities:

- **voice** We naturally use our vocal apparatus to imitate sound textures of many kinds, including those produced by continuous contacts of an object with a surface;
- **synthesis** Several techniques are available to (re-)synthesize sound textures [7];
- **fractals** Many surfaces can be approximated by means of fractal noise [6].

sound (vibration) $\rightarrow$ **image** An audio or a haptic signal (of one variable) can be used to produce an image in many different ways. One trivial yet useful transformation is the stacking of luminance-translated audio signals to produce rows of pixels. Another interesting image could be obtained by arranging such audio signals according to polar coordinates, thus getting something similar to the cross section of a tree trunk. Each of these sound-to-image transformations affords different kinds of subsequent image-based exploration of the sound material (e.g., temporal expansion, inversion, interlacing).

Modeling the exploration of textures

Textures can be explored by:

- scraping
- rubbing
- rolling

All of these actions can be described by microscopic contact events occurring between the probe and the explored surface, that can be simulated by impact and friction models. The auditory-tactile feedback of Sketch a Scratch relies on two physics-based real-time models which render respectively impact and stick-slip friction phenomena [6]. In particular, when a sharp object comes into contact with a surface at a small number of points, producing micro-impact and stick-slip friction events, we have scraping. Conversely, rubbing is produced when the probe size and shape determine a large number of simultaneous micro-collisions, resulting in increased stick-slip friction. A rolling sound emerges from the probe bouncing from contact to contact, with minimal stick-slip friction contribution. Moreover, thanks to the dynamic nature of the models used in this work it is possible to seamlessly morph among such interaction modalities.

Impact model
The impact model describes two bodies colliding, more precisely a point-mass (exciter) and a resonating object. The contact force f_i is a function of the object compression x and compression velocity $\dot{x}$, and depends on parameters such as the object elasticity, mass, and local geometry around the contact surface:

$$f_i(x, \dot{x}) = \begin{cases} -kx^{\alpha} - \lambda x^{\alpha} \dot{x}\,, & x > 0 \\ 0\,, & x \leq 0 \end{cases} \tag{1}$$

where k accounts for the material stiffness, λ represents the force dissipation, and α describes the local geometry around the contact surface. When $x \leq 0$ the two bodies are not in contact.

In the present implementation, a surface profile modulates the relative displacement offset between the probe and the resonating object, while the normal force applied to the probe is also used to feed the impact model.

Friction model
The friction model describes the relationship between the relative tangential velocity v of two bodies in contact, and the produced friction force f_f. The model assumes that friction results from a number of microscopic elastic bristles, accounting for stick-slip phenomena:

$$f_f(z, \dot{z}, v, w) = \sigma_0 z + \sigma_1 \dot{z} + \sigma_2 v + \sigma_3 w \tag{2}$$

where z is the average bristle deflection, $\dot{z}$ the average bristle deflection velocity, the coefficient σ_0 is the bristle stiffness, σ_1 is the bristle damping, and the term $\sigma_2 v$ accounts for linear viscous friction. The noise component $\sigma_3 w$ represents surface irregularities.

Since tangential motion, together with the normal reaction force f_i generated by micro-impacts, can elicit stick-slip phenomena, the latter can be recreated by the friction model. Considering a single impact and a small portion of surface profile having slope δ around the contact point, the impact force f_i is returned along the direction normal to such slanted surface. Its horizontal component $f_i \sin\delta$ can be derived and used to drive the sliding force parameter of the friction model [4] and, similarly, the vertical component $f_i \cos\delta$ can be used in the friction model to control the normal pressure over the surface.

Output

The impact and friction models synthesize vibratory signals, which can be output as sound to render the aural manifestation of texture exploration. Such signals can also be used to drive a shaker and effectively render vibrotactile texture. The model dynamics also produce forces which can be rendered through a haptic device.

In the current prototype a graphic tablet is actuated, and the vibration propagates on a framed transparent plastic foil that is superimposed on the image, or visual display. The actuator can be a DC motor, which is especially effective for slow movements, or a voice coil driven by the low-frequency components of the audio output. It is also possible to mount a haptic actuator directly on the probe [4].

Realization

The present realization includes a Max/MSP patch based on the Sound Design Toolkit [2], a Wacom Intuous 2 USB tablet and stylus, and a Precision Microdrives 312-101 DC motor driven via Arduino Uno.

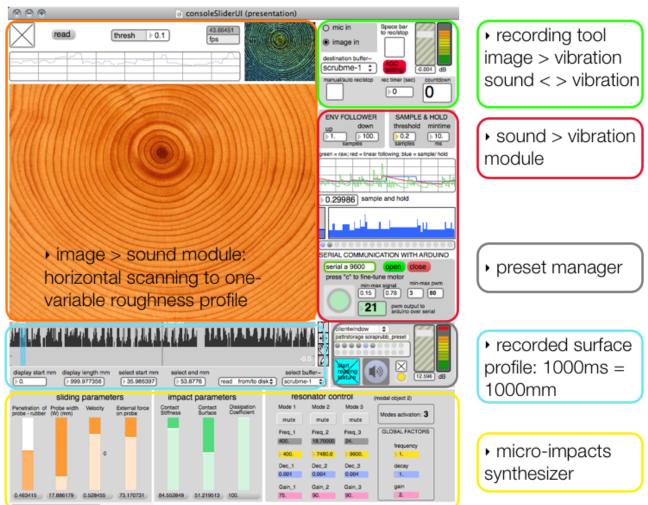

Figure 2: GUI for Sketch a Scratch

The graphical user interface (Fig. 2) allows one to load images, record audio tracks, and turn them into surface profiles. These can be explored with virtual probes of different characteristics, thus simulating scraping, rubbing, or rolling. In our realization, exploration can be either automatic (passive), or manually driven through the stylus (active). The resulting texture signal is used to pulse-width modulate the speed of the vibration motor, thus providing both acoustic and vibrotactile output.

image → sound module (orange box): visual surfaces can be loaded and edges highlighted by image processing. Horizontal mouse scanning converts luminance values into an audio signal, and this can be recorded as reference roughness profile.

recording tool (green box): up to six different roughness profiles can be recorded as audio signals and recalled, to drive the synthesis engine. The signals' buffer length is 1000 ms, ideally corresponding to 1000 mm. Recording can be done manually, by pressing the space bar on the keyboard, or automatically, by specifying a duration. A set of radio buttons allow one to choose among different input strategies and signal chains, from [image → sound], to [vibration → sound] (e.g., scraping a surface with a contact microphone), and [sound → vibration] (e.g., by means of vocalizations). Automatic gain control is used to adjust the input signal to a suitable level.

micro-impact synthesizer (yellow box): the modes of resonance of the single impact are specified in the "resonator control" box, according to their frequency, decay and gain parameters. The "impact parameters" describe the quality of the single collision (stiffness, sharpness, and energy dissipation affecting the occurrence of bouncing phenomena). The "sliding parameters" layer is used to interpret the stored surface profile and drive the impact model accordingly. The vertical penetration of the probe sets the threshold level of the roughness profile above which the signal is detected, while the probe width parameter sets the size of the sliding window on the roughness profile (in mm, large = rubber, small = sharp object). The probe is advanced every Δt ms by a distance $\Delta x = v\Delta t$, where v is the sliding velocity in m/s. The detected pressure of the stylus is used to control the penetration of the virtual probe, while the differential of the polar coordinates of the stylus on the tablet is mapped on the velocity parameter. Additional parameters (not displayed in Fig. 2) are Δt in ms and the diameter of a single contact area in cm.

sound → vibration module (red box): the synthesized audio signal is used to drive a shaker and provide vibrotactile output. An envelope follower and a sample-and-hold unit are used to discretize the signal and make it suitable to control a DC motor.

Demonstration

Sketch a Scratch is demonstrated with a tablet-based interface embedding visual, vibratory, and acoustic display. Work is in progress along the following directions:

- Improving the connection between the impact and friction sound models. This is crucial for an effective rendering of the perceptual qualities of roughness, hardness, and stickiness [3];
- Experimenting with 2D visualizations of vibratory or audio textures. Visually derived textures would afford active, indirect and possibly performative exploration and re-interpretation of the raw materials;
- Experimenting with different haptic and vibratory actuators. At the moment, the vibration motor is particularly effective for slow scanning, being unable to follow rapid gestures;
- Using Sketch a Scratch as a tool to investigate the effectiveness of vocal sketching and vocal imitations.

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