To “Sketch-a-Scratch”

A. Del Piccolo[1], S. Delle Monache[2], D. Rocchesso[2], S. Papetti[3], and D.A. Mauro[2]
[1]Ca’ Foscari University of Venice, Department of Environmental Sciences, Informatics, and Statistics
956199@stud.unive.it
[2]Iuav University of Venice, Department of Architecture and Arts
sdellemonache, roc, dmauro@iuav.it
[3]Zürcher Hochschule der Künste, Institute for Computer Music and Sound Technology
stefano.papetti@zhdk.ch

ABSTRACT

A surface can be harsh and raspy, or smooth and silky, and everything in between. We are used to sense these features with our fingertips as well as with our eyes and ears: the exploration of a surface is a multisensory experience. Tools, too, are often employed in the interaction with surfaces, since they augment our manipulation capabilities. “Sketch-a-Scratch” is a tool for the multisensory exploration and sketching of surface textures. The user’s actions drive a physical sound model of real materials’ response to interactions such as scraping, rubbing or rolling. Moreover, different input signals can be converted into 2D visual surface profiles, thus enabling to experience them visually, aurally and haptically.

1. INTRODUCTION

In everyday interaction with the environment, we experience surface textures mostly through touch and vision, although audition can contribute to forming multisensory percepts too [1]. Textures can be rubbed with a fingertip, scraped with a nail, or rolled-over with a ball. All of these actions can be described by microscopic contact events occurring between the probe (be it the finger itself, or an object such as a pen) and the explored surface. These events can be simulated by the physical modeling of impact and friction phenomena in order to reproduce in a virtual setting the experience of interacting with a surface texture.

The importance of haptics for conveying a convincing textural experience in virtual and augmented environments has been widely advocated [2], although force-feedback devices are impractical or expensive in many contexts. This explains the emergence of pseudo-haptics [3,4], i.e. the exploitation of multisensory illusions to render forces through alternative sensory channels.

When performed with a tool, the exploration of a surface often produces an audible signal that carries information about surface roughness, hardness, and friction through sound [1]. On the other hand, a sound signal can be interpreted as a surface profile that may be appreciated with other senses. Hence, the qualities of a surface can be imposed by means of synthesized or acquired sound signals.

In addition, co-location of action and feedback is a crucial factor, as it recalls the typical situation of many manual activities that afford the development of expressiveness and virtuosism, such as painting or drawing.

Investigating the multisensory exploration of a virtual surface can provide clues on how the sensory channels integrate in the forming of similar experiences in the real world. Through these channels, different aspects of complex physical phenomena are rendered. While some of these aspects may be impossible or impractical to render accurately in a digital environment, their modeling helps investigating how they might possibly be replaced or imitated by means of other sorts of stimuli. For instance, some haptic sensations, i.e. the lateral forces [5], which are usually not conveyable through easily accessible devices, require alternative solutions in order for them to be sensed.

We present “Sketch-a-Scratch”, an experimental tool for multisensory sketching and augmented exploration of surface textures. This apparatus is based on a vibroacoustically augmented graphic tablet and stylus, and on real-time physics-based simulation of contact mechanics, and can render surface textures by means of visual, auditory, and vibratory feedback. Multimodal exploration and modeling of virtual surfaces coexist in that the user can acquire a surface texture from various sources, from still images to drawing, from audio recordings to vibration sensing, and hence experience them through probe-mediated touch, vision, and audition. The tool allows to transform these actions into performative acts, and finally experience and exploit surface qualities across different modalities.

The paper is organized as follows. First we describe the research background of Sketch-a-Scratch, and the motivations behind it, that is the multisensory exploration of virtual surface profiles. Then, we describe the concept and the general architecture of the tool. Further on, the basic framework that we devised for experimentation is illustrated, as well as its hardware and software requirements. We then outline two contexts of use for the tool, namely an artistic performance and a self-contained interactive installation. The different contexts of use trace the path of our investigation on tool-mediated exploration and design of virtual surfaces. We especially elaborate the experience gathered by the public installation showcase and outline some possible directions for future development of the tool.

2. BACKGROUND

Surfaces can be experienced visually, when they are acquired as pictures, or haptically through a process of scanning.

The haptic sensation of a surface can be provided by actuating either the surface [6] or the probe [7]. An alternative to the mechanical actuation is the use of electricity-induced vibrations in different forms: electrocutaneous [8], electrostatic [9] or electrovibration [10].

Direct touch differs from tool-mediated exploration in that the former gives a spatial, intensive measure of roughness, while the latter carries information about roughness, hardness and friction in the form of a multidimensional signal in the time variable. In the more traditional category of mechanically-induced haptic feedback, the actuation of the interactive surface by means of piezoelectric bending motors, voice coils or solenoids [11] allows for direct touch, yet presents several drawbacks. Due to the flexibility of the surface, the feedback is usually not uniform throughout the active area, especially with large surfaces. Besides, motors are often located on the sides of the surface, which makes it hard to convey the co-location of stimulus (the user's touch) and response (the vibration).

The tool-mediated exploration of a surface is a common practice in many creative processes such as writing and figurative art. When using this paradigm for digital simulation it also presents practical advantages. The actuator for haptic feedback can be incorporated in the probe, making the intensity of the feedback independent from size and geometry of the screen. Moreover, the round, plastic tip of a stylus exerts less friction than the finger tip on the glass surface of a touch screen. Starting from a situation of reduced inherent friction, the implementation can achieve a wider range of levels of friction.

In sound synthesis, contact phenomena taking place at the interface between an object and a surface can be simulated by means of several models. One type of such phenomena is friction, which is based on stick-slip commutation [12]. Other types, such as rolling, are rendered by patterns of impacts [13]. In those models, surfaces are often specified as one-dimensional height profiles, either sampled or algorithmically generated.

Visually, the exploration of a surface has its salient points in the regions of maximal change, e.g. in brightness or colour, which may represent tangible discontinuities such as ridges. In the same way, the evenly-coloured parts of the image represent flat parts of the surface. It is therefore possible to detect visual cues and use their parameters in order to drive other forms of feedback and their intensity (e.g. loudness of a scraping sound, intensity of a vibratory impulse). As a consequence, the representation of any kind of input as a visual surface enables its later multisensory exploration.

The most direct way to accurately replicate the experience of a tangible texture is by modeling the mechanical events which are originated during the exploring action. This modeling must take into account variables such as the local geometry of the surface around the point of contact between probe and surface, or local energy dissipation, which depends on the material.

A dynamic impact model for synthesizing scratching, rubbing and rolling sound-actions has been developed by Conan et al. [14, 15]. Impacts are distributed in time and controlled in amplitude according to stochastic models of these actions. Another synthesis engine is the Sound Design Toolkit [16], which offers a set of physics-based sound algorithms organized according to an ecological taxonomy of everyday sounds. Merrill et al. [17] proposed the gestural exploration of physical surfaces as means to drive the sound synthesis. By brushing, scraping, striking, etc. on physical textures it is possible to control the continuous playback and modification of prerecorded audio samples.

Sketch-a-Scratch aims at reconstructing the surface exploration experience by exploiting the Sound Design Toolkit as a basis for modeling the reaction of different materials to probe contact. The visual texture can be generated by means of image acquisition, real surface scanning, or by the interpretation of audio recordings as surface profile. One immediate use of the audio recordings consists in translating the temporal envelope of a sound into spatially linear information.

3. THE "SKETCH-A-SCRATCH" CONCEPT

Sketch-a-Scratch is an abstract experimental workbench conceived to explore several research-through-design topics: Sonic sketching of surface qualities; creative texture modeling and multimodal exploration; exploration of auditory contents rendered by means of auditory, visual and tactile feedback.

In this paper we focus on the contributions of visual, auditory, and haptic feedback in the probe-mediated exploration of surface textures (see Section 5.2). Aspects such as the interaction style and the qualities of real materials in terms of force dissipation are taken into account, as well as the peculiarities of a single surface. Visual, auditory, and haptic feedback channels are composed to simulate and reconstruct the experience of the contact with a real surface.

The interaction takes place over an interactive surface, namely the touch screen of a tablet, on which a digitized texture is displayed. The user runs the tip of a vibrotactile-augmented stylus on the screen. A physical sound model of a real material (e.g. wood, glass, dry soil) is driven by the exploration of the different features of the surface such as even areas, bumps, creases and ridges. A sound output is consequently generated in real-time, as well as vibrations for the stylus. A local visual deformation helps keeping track of the contact position between probe and screen, and completes the multisensory experience. An overview of the whole system is depicted in Figure 1.

The qualities of a surface can be sketched through several alternative representations of a texture:

- a digital image, whose regions of maximal change of grey-level are interpreted as depth shifts such bumps

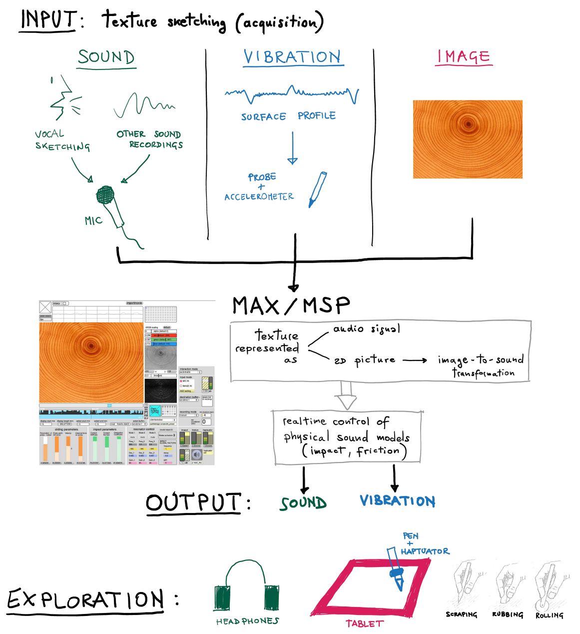

Figure 1. Sketch-a-Scratch concept.

and ridges;

- an audio signal, e.g. a vocal recording, whose features can be preliminarily converted into a visual mesh and finally interpreted as a map;
- a vibration, which can be generated by scanning a real surface with a probe to acquire its linear profile.

The system affords various types of contact (styles of interaction): scraping, rubbing and rolling, obtained by specific combinations of an impact and a friction model. The sensory cues are meant to be synchronous and coherent: A vibrating motor attached close to the stylus tip co-locates the haptic feedback at the point of contact with the surface, whereas intensity and frequency of sonic and vibratory impulse are generated proportionally with the gradient of gray-levels in the area of the image that is being crossed by the stylus.

4. THE "SKETCH-A-SCRATCH" FRAMEWORK

Sketch a Scratch uses an impact model that describes two colliding bodies [12]: a point-mass (exciter) and a resonating object. The contact force f_i is a function of the object compression x and compression velocity $\dot{x}$:

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

where k accounts for the object 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 addition, a friction model is used, which describes the relationship between the relative tangential velocity v of two bodies in contact, and the produced friction force f_f. In what follows the exciter is called "rubbing" object while the resonator is called "rubbed" object. The model assumes that friction results from a number of microscopic elastic bristles, accounting for stick-slip phenomena:

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

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. In particular the variable z describes the three regimes accounted for by the model:

elastic: the rubbed object is fixed and does not vibrate, while the rubbing object moves tangentially;

elasto-plastic: the rubbed object vibrates, while the rubbing object moves tangentially;

plastic: the rubbed object does not vibrate and is dragged by the rubbing one.

The two models are used in conjunction to simulate complex vibratory phenomena. A simulated surface profile is used in the impact model to modulate the relative displacement offset between the exciter and the resonating object (i.e., the stylus and the surface). The normal force applied to the stylus is also used to feed the impact model. In addition, when driven by the stylus' tangential motion and the normal reaction force f_i produced by the simulated microimpacts, the friction model generates stick-slip phenomena.

The impact and friction models produce vibratory signals, which can be output as sound, to render the aural manifestation of texture exploration, as well as used to drive a vibration transducer. The model dynamics also produce forces which can be rendered through a haptic device. Similarly to what done in [18], the stylus is actuated by means of a vibrotactile transducer driven by the low-frequency components of the synthesized audio output. The main components of the system are a Max/MSP patch based on the Sound Design Toolkit [16] running on a Apple laptop, a 13.3" Wacom Cintiq graphic tablet (1920$\times$ 1080 pixels) and stylus, and a TactileLabs Haptuator Mark II vibrotactile transducer attached to the stylus. For a localized emission of sound and vibration, a dynamic speaker is attached to the back of the tablet and wired to one of the two channels of a Sonic Impact T-Amp amplifier, the other channel being connected to the vibrotactile transducer. Audio signal acquisition is performed via an external microphone, that can be replaced by a portable digital audio recorder for its versatility.

Figure 2 shows the graphical user interface. It allows to load images, record audio tracks, and turn them into surface profiles. Different kinds of virtual materials (e.g. glass-like, metallic, wooden) and interactions (e.g. bouncy, sticky) can be synthesized and saved as presets. 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 a 1000-mm-long surface. The 'impact parameters" describe the quality of the single collision (stiffness, sharpness, and energy dissipation affecting the occurrence of bouncing phenomena). The "sliding parameter" 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. Additional parameters (not displayed in Fig. 2) are Δt in ms and the diameter of a single contact area in cm.

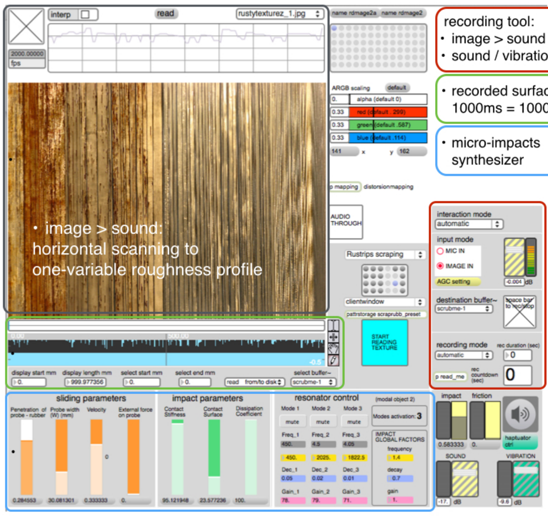

Figure 2. Sketch-a-Scratch GUI.

Thus, the profiles can be explored with virtual probes of different characteristics, to simulate scraping, and rubbing. In our realization, exploration can be either automatic by acting on the GUI (passive), or manually driven through the stylus (active).

In particular, the tilt of the stylus is exploited in active exploration to virtually change the configuration of the probe (i.e., the width), thus shifting the interaction style from scratching (stylus perpendicular to the screen) to rubbing (maximum tilt of the stylus). This feature represents a convenient way to foster the expressiveness of the tool during performative acts. Furthermore, the vertical force relative to the stylus' tip on the screen is used as a control of the vertical penetration of the probe on the virtual surface profile.

Audio or vibrotactile signals (of one variable) can be used to produce an image in different ways. One trivial yet effective transformation used in our tool is the stacking of luminance-translated audio signals to produce rows of pixels. As an example, the four rows, shown in Figure 3, represent the visual textures resulting by the transformation of four different sounds, originated by the vocal imitation of different impact noises (knocks, rolling, sawing, splatters, from top to bottom), each of a duration of 5 seconds.

This sound-to-image transformation affords different kinds of subsequent image-based exploration of the sound material (temporal expansion, inversion, interlacing, etc.). In addition, a local image deformation is applied at the point of interaction to mimic superficial vertical and lateral forces exerted by the stylus.

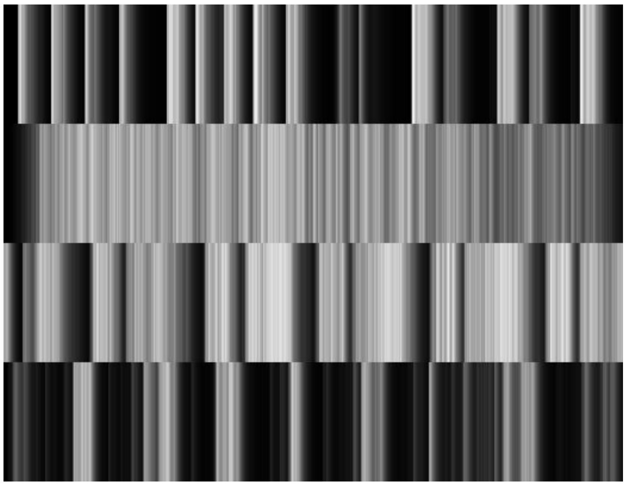

Figure 3. Example of sound-to-image transformations, from top to down: first row, knocks; second row, rolling; third row, sawing; fourth row, splatters.

5. "SKETCH-A-SCRATCH" IN ACTION

The basic configuration served as workbench to investigate the potential of Sketch-a-Scratch in different contexts of use, and for a variety of purposes: demonstrations, experimental research, live performances and installations.

In [5] we exploited the experimental workbench to find quantitative behavioral evidences of the effectiveness of image, sound and vibration as sensory substitutes of lateral forces in texture exploration tasks.

In this paper we focus on the exploitation of Sketch-a-Scratch as a performative tool and as a public installation. The performance setting aimed at sharing with an audience the intimate qualities of contact actions through listening, while the public installation enabled us to test the effectiveness of the multisensory rendition of the surface exploration.

5.1 Performance

Any tool that affords expressive manipulation will become, sooner or later, a device for artistic performance. Many examples are found in the history of musical instruments, from hunting bows converted to string exciters, to turntables converted to expressive scratching instruments [19].

The potential of Sketch-a-Scratch as a device for artistic performance was tested in a public performance in the occasion of the 2014 World Voice Day [1]. In that public event, two exemplars of Sketch-a-Scratch [2] were played by a quartet, as depicted in Figure 4. One vocalist provided vocal textures that were cyclically explored while

[1] http://en.wikipedia.org/wiki/World_Voice_Day.
[2] A video footage is also available at https://vimeo.com/93417532

the impact and friction parameters were dynamically manipulated by another performer. One drawer acted with the stylus on the tablet to explore four different kinds of material textures, each corresponding to one movement of the piece, under the direction of a fourth laptop performer.

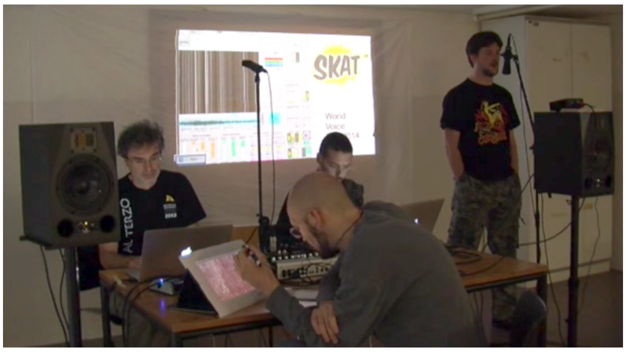

Figure 4. Performance rehearsal for The 2014 World Voice Day. One drawer (front side of the table) is exploring a material texture, while a vocalist (right, standing) is providing vocal textures. Two performers (back side of the table) are manipulating the impact and friction parameters in real time.

Similarly to what happens with musical instruments that are designed around tangible user interfaces [20], the engagement of a performer that is acting on the interactive surface and receiving localized feedback is transferred to the audience by means of body movements, visual projection of the interface, and aural result.

In Sketch-a-Scratch, the auditory feedback is consistent with the performer's actions, and communicates expressive sonic gestures about touch, an experience which is normally personal and non-sharable.

The performing quartet can be seen as a double duo, each duo being formed by a (voice or pen) source performer and a manipulator. As opposed to the usual practices of live electronics, however, the manipulator does not modify the audio material directly. Instead, the manipulator can either select and adjust the textures for pen-based exploration, or use the vocal material as textures to be explored by virtual probing.

5.2 Installation

Sketch-a-Scratch was also showcased as a self-contained interactive installation [3], aimed at demonstrating the contributions of visual, auditory and haptic feedback in the experience of tool-mediated exploration of surface textures. The occasion for this showcase was an academic celebration day including demonstrations, lectures, awards, and gourmet buffet. Like other demonstrations, our installation served as inspiration for the chefs invited to show their food designs.

Given the number of expected participants, and thus the natural presence of a loud background noise, and since the time of stay per visitor was expected to be quite short, both auditory and haptic feedback were exaggerated, in order to provide the Sketch-a-Scratch experience at a glance. Visitors were free to use the stylus to virtually scratch and scrape on four different surface textures displayed on the screen of the vibro-acoustically-augmented tablet. The audience was prompted to explore and savor bumps, ridges and creases, enriched by a vibro-acoustic feedback coherent with the material characteristics of the 2D image displayed on the screen (e.g. plastic, wood, glass). In addition, visitors could also record short audio excerpts, their voice for instance, and interact with the resulting virtual profile. The latter feature was aimed at stressing the richness of one's own vocal capabilities, by providing an immediate engagement in the design of surface textures.

The exhibition let us record valuable observations for further development of the tool. Video recordings, direct observations, talking-aloud impressions and post hoc comments by the visitors, especially regarding their own expectations, were collected in order to revise the system, improve the effectiveness of the interaction, and devise new creative and functional scenarios.

5.2.1 Design

Figure 5 shows the box that we designed to host our system. Sketch-a-Scratch shows up in the empty room as a monolith representing four different textures.

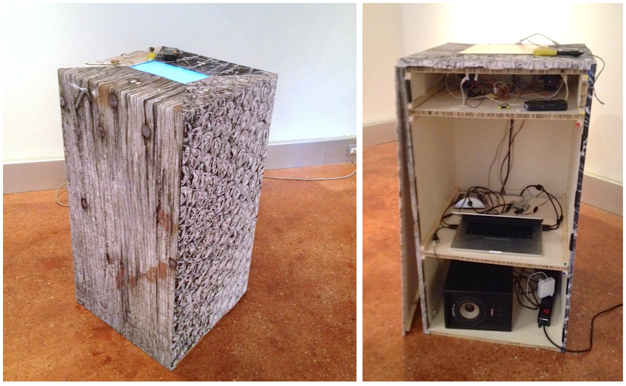

Figure 5. Sketch-a-Scratch installation. On the right, details of the hardware embedded in the box.

As shown in Figure 6, each side of the parallelepiped is covered with a print of a macro-image of a texture surface, namely bubble wrap, broken glass, wooden board, and cracked ground. The four textures were chosen in order to elicit diverse interactive experiences, and possibly prompt different responses and interaction styles or, in other words, gestures. In addition, a well-refined tweaking of the impact and friction parameters was aimed at strengthening the expectations and interaction with the materials displayed. The shell was designed in order to hide all the hardware, and to afford an interaction as natural and ecological as possible.

Users only had to handle the stylus, and start sketching their scratches on one of the four textures at a time or on the voice generated surface profile. The stylus was modified and the tip camouflaged, in order to reduce the effect of the typical affordances of the pen. In addition, users were prompted to hold the stylus between their index and middle

[3] `https://vimeo.com/111889017`

Figure 6. Macros of the four textures available for exploration: bubble wrap (top-left), broken glass (top-right), wooden board (down-left), cracked ground (down-right).

finger, to avoid the metaphor of writing and facilitate the full experience of touch.

Visitors could browse the available textures on the display by positioning a token on one of the four switches located on the table top, each associated to one side of the shell. The switches were implemented as simple open circuits painted on paper with conductive ink [4]. In Figure 7 it is possible to observe the two rounded electric terminals, placed at the centre of the wooden surface, and the token positioned on the bubble wrap texture.

Finally, users could record their voice by approaching a clearly-visible digital audio recorder, and engage in direct explorations of their sketches.

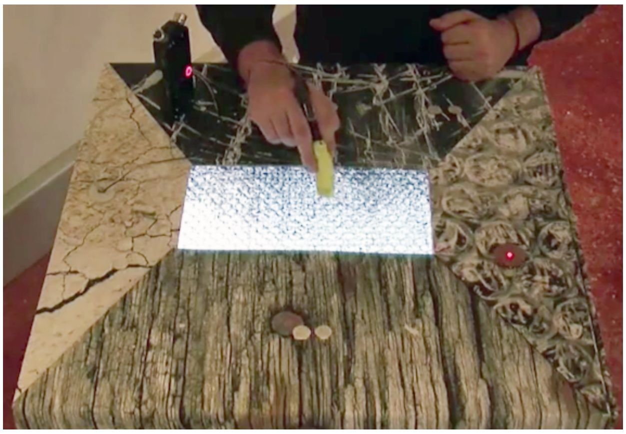

Figure 7. Top of the installation with tablet, stylus and audio recorder. The rounded token with the red led allows to browse and switch between the four textures.

In order to achieve the co-location of visual, auditory and haptic feedback, two small loudspeakers were placed on a shelf just below the tabletop. However, given the presence of a loud background noise, we reinforced the auditory feedback by adding an active speaker, which was placed on the bottom of the box. As a result, the friction sounded darker than what one would naturally expect from real-world situation. The haptic feedback was also reinforced accordingly.

5.2.2 *Observations*

We filmed the interaction with the installation by the most engaged visitors (12, 7 male and 5 female, average age 30), i. e. those who lingered enough time to acquire a basic understanding of the system and of its features. Environmental noise made comments almost inaudible, nonetheless several interesting comments were extracted. For instance, a professor of modern art history advocated the application of the Sketch-a-Scratch framework to the enhancement of navigation experience in art galleries for the visually impaired. Regarding the movements the visitors employed, different styles of interaction were displayed (see Figure 8), from the regular, neat stroke of a painter to the irregular touch intensity shown by non-trained individuals.

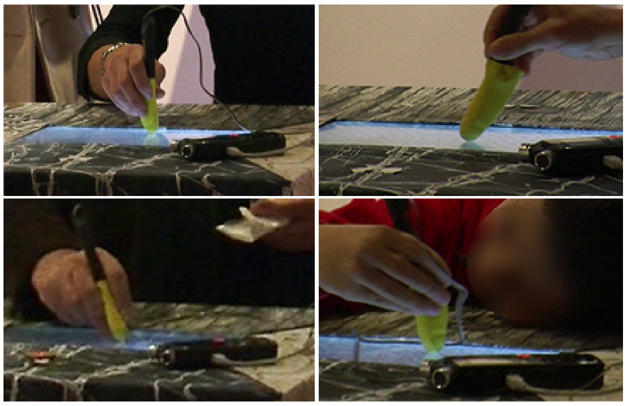

Figure 8. Different styles of interaction employed by visitors. From top left, clockwise: vertical popping, painter-like slanted stroking, quick scribbling, slow crossing of the texture's features.

In general, the installation was positively received. Direct observations of the visitors performing on Sketch-a-Scratch revealed a variety of personal and creative explorations. For instance, many users challenged the expressiveness of the local deformation of the image at the tip of the stylus and started "popping" the virtual surface. This behavior was especially evident in the case of the bubble wrap texture where users try to mimic the usual behavior. Many visitors commented the "popping" on virtual bubble wrap as an accurate and fun experience. Other users focused on the responsivity and fidelity of the feedback, e.g. by crossing slowly the cracks on the glass texture. Some minor latencies were reported. However, this can be attributed not only to the system, but also to the larger size of the "eraser" tip (compared to the pen tip), which reduces the friction on the display, though at the cost of a less accurate detection of the impacts. In addition, among the three sensory feedbacks, the haptic feedback took by surprise most of the users, at the same time being assessed as the most effective.

The auditory feedback was well received too, although

[4] The conductive ink and the magnetic led component are part of the Circuit Scribe system: `http://www.123dapp.com/circuitscribe`.

most of the comments were spurred by the vibrotactile feedback. Residual inaccuracies in the auditory response were not deemed as important, thus suggesting that users were more focused on visuals and haptics than on sounds. However the presence of a coherent sound played a role in augmenting the immersiveness of the experience. Specifically, the images were more appreciated as a navigation guidance than as a feedback source. The local distortion at the contact point of the tip on the surface went barely noticed, although they were crucial in letting the ”popping” affordance emerge.

The audio sketching mode was received with milder interest due to its lower degree of immediacy, especially when the visitors were prompted to expose their body and voice in public. Most users were more prone to attend demonstrations of vocal sketching than to try it themselves in presence of others. Nevertheless, the audience was intrigued by the potential of the sketching tool and of the possible development and applications. Moreover, comments stressed a generally clear understanding of the causal link between the vocal gesture and its visual rendition: after a brief explanation, the visitors could recognize the visual impression of simple vocalizations, such as sustained sounds, rhythmic patterns, trills, etc.

6. CONCLUSIONS AND FUTURE WORK

We introduced Sketch-a-Scratch, a multisensory tool for probe-mediated sketching and exploration of augmented surfaces. The tool is currently being exploited as a framework to investigate the perceptual and cognitive aspects involved in the probe-mediated experience of (virtual) surfaces, and to expose the affordances and inherent expressiveness of this kind of interaction for design purposes and performative uses.

The rendering of this experience in virtual environments, such as ordinary interactive flat visual displays, requires effective strategies of augmentation, in terms of both actuating technology and design choices in feedback manipulation. In Sketch-a-Scratch, a strategy based on a physically-informed approach to sound synthesis and pseudo-haptics resulted effective in conveying the salient aspects of contact phenomena such as scraping and rubbing.

At the same time, the experiences collected with the current configuration of our tool, and in its diverse contexts of use, also highlighted the limits of virtualization. Coherent multisensory stimuli certainly increase naturalness in the interactions with virtual surfaces, resulting in a higher expressiveness during creative efforts. However, the actual lateral forces that are experienced when scraping a real surface with a tool remain hard to reproduce with sensory illusions; in addition, the visual feedback plays a predominant role over auditory and haptic feedback in trajectory-based tasks [5]. On this standpoint, we will investigate the effectiveness of our vibroacoustic augmentation approach of flat displays in conjunction with 3D textures. In particular, by superimposing a thin 3D texture on the display, the two-dimensional information (i.e., speed and location of the stylus) extracted by the Wacom can be integrated with the stylus information (i.e., tilt and force) deriving from the actual interaction with the real asperities of the overlay. We are currently making some explorations with 3D textures of few millimeters of thickness. For example, Figure 9 shows a three-dimensional realization of the four vocal imitations depicted in Figure 3. A 3D print of this tile was already used in public demonstrations to sensitize the participants to “real” probe-mediated texture exploration and to give a concrete example of what “scraping a vocal sound” means in practice [21].

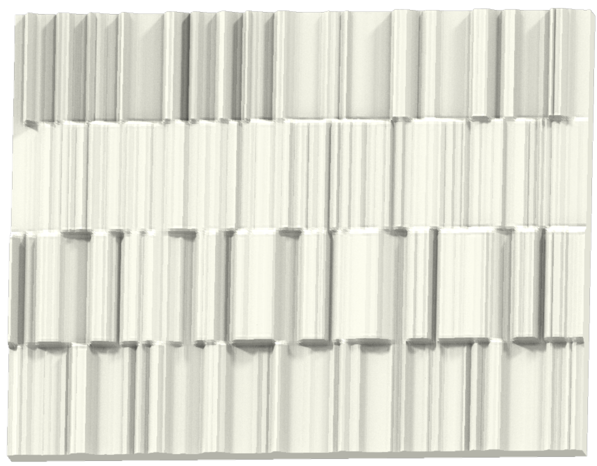

Figure 9. Rendering of the 3D printed texture representing the profiles derived from the sound-to-image transformations depicted in Figure 3.

Sound and vibration can be exploited to enhance the experience of creative acts such as painting and drawing, when these activities are performed on interactive surfaces. In addition, the stylus could be used not only as a probe, but also as an active tool for texture manipulation. A designer might wish to flatten or curl a region of the virtual surface, or to displace it. Finally, the integration of vocalizations in the sketching process might lead to a scenario where voice and hands are in a continuous conversation, thus collaborating seamlessly in the molding of the creative result. In this respect, Sketch-a-Scratch is a modulator of problem space, and serves as an open workbench for our design research in virtual texture modelling.

Acknowledgments

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7. REFERENCES

[1] R. L. Klatzky and S. J. Lederman, “Multisensory texture perception,” in *Multisensory object perception in the primate brain*, M. J. Naumer and J. Kaiser, Eds. Springer Verlag, 2010, pp. 211–230.

[2] G. Robles-De-La-Torre, “The importance of the sense of touch in virtual and real environments,” *IEEE Multimedia*, vol. 13, no. 3, pp. 24–30, 2006.

[3] A. Lécuyer, “Simulating haptic feedback using vision: A survey of research and applications of pseudo-haptic feedback,” *Presence: Teleoperators and Virtual Environments*, vol. 18, no. 1, pp. 39–53, 2009.

[4] K. V. Mensvoort, P. Vos, D. J. Hermes, and R. V. Liere, “Perception of mechanically and optically simulated bumps and holes,” *ACM Trans. Appl. Percept.*, vol. 7, no. 2, pp. 10:1–10:24, Feb. 2010. [Online]. Available: http://doi.acm.org/10.1145/1670671.1670674

[5] D. Rocchesso, S. Delle Monache, and S. Papetti, “Multisensory texture exploration at the tip of the pen,” *Special Issue on Data sonification and sound design in interactive systems*, 2015.

[6] M. Fukumoto and T. Sugimura, “Active click: Tactile feedback for touch panels,” in *Proceedings of CHI 2001*. ACM, 2001, pp. 121–122.

[7] J. Lee, P. Dietz, D. Leigh, W. Yerazunis, and S. Hudson, “Haptic pen: A tactile feedback stylus for touch screens,” in *UIST'2004*. ACM, 2004, pp. 291–294.

[8] K. Kaczmarek, J. Webster, P. Pach-y Rita, and W. Tompkins, “Electrotactile and vibrotactile displays for sensory substitution systems,” *IEEE Transactions on Biomedical Engineering*, vol. 38(1), pp. 1–16, 1991.

[9] A. Yamamoto, S. Nagasawa, H. Yamamoto, and T. Higuchi, “Electrostatic tactile display with thin film slider and its application to tactile telepresentation systems,” *IEEE Transactions on Visualization and Computer Graphics*, vol. 12(2), pp. 168–177, 2006.

[10] O. Bau, I. Poupyrev, A. Israr, and C. Harrison, “Teslatouch: Electrovibration for touch surfaces,” in *UIST'2010*. ACM, 2010.

[11] F. Giraud, M. Amberg, B. Lemaire-Semail, and G. Casiez, “Design of a transparent tactile stimulator,” in *IEEE Haptics Symposium 2012*. IEEE, 2012, pp. 121–122.

[12] F. Avanzini, S. Serafin, and D. Rocchesso, “Interactive simulation of rigid body interaction with friction-induced sound generation,” *IEEE Trans. Speech and Audio Proc.*, vol. 13, no. 5, pp. 1073–1081, Sept 2005.

[13] M. Rath and D. Rocchesso, “Continuous sonic feedback from a rolling ball,” *IEEE Multimedia*, vol. 12, no. 2, pp. 60–69, 2005.

[14] S. Conan, E. Thoret, M. Aramaki, O. Derrien, C. Gondre, R. Kronland-Martinet, and S. Ystad, “Navigating in a space of synthesized interaction-sounds: rubbing, scratching and rolling sounds,” in *Proceedings of the 16th Int. Conference on Digital Audio Effects*, Maynooth, Ireland, Sep. 2013. [Online]. Available: http://dafx13.nuim.ie/papers/32.dafx2013_submission_43.pdf

[15] S. Conan, E. Thoret, M. Aramaki, O. Derrien, C. Gondre, S. Ystad, and R. Kronland-Martinet, “An intuitive synthesizer of continuous-interaction sounds: Rubbing, scratching, and rolling,” *Computer Music Journal*, vol. 38, no. 4, pp. 24–37, 2014.

[16] S. Delle Monache, P. Polotti, and D. Rocchesso, “A toolkit for explorations in sonic interaction design,” in *Proceedings of the 5th Audio Mostly Conference: A Conference on Interaction with Sound*, ser. AM '10. New York, NY, USA: ACM, 2010, pp. 1:1–1:7. [Online]. Available: http://doi.acm.org/10.1145/1859799.1859800

[17] D. Merrill, H. Raffle, and R. Aimi, “The sound of touch: physical manipulation of digital sound,” in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, ser. CHI '08. New York, NY, USA: ACM, 2008, pp. 739–742. [Online]. Available: http://doi.acm.org/10.1145/1357054.1357171

[18] C. G. McDonald and K. J. Kuchenbecker, “Dynamic simulation of tool-mediated texture interaction,” in *World Haptics Conference (WHC), 2013*. IEEE, Apr. 2013, pp. 307–312. [Online]. Available: http://dx.doi.org/10.1109/whc.2013.6548426

[19] J. Sterne, “Media or instruments? yes,” *Offscreen*, vol. 11, no. 8-9, 2007. [Online]. Available: http://offscreen.com/view/sterne_instruments

[20] S. Jordà, G. Geiger, M. Alonso, and M. Kaltenbrunner, “The reactable: Exploring the synergy between live music performance and tabletop tangible interfaces,” in *Proceedings of the 1st International Conference on Tangible and Embedded Interaction*, ser. TEI '07. New York, NY, USA: ACM, 2007, pp. 139–146. [Online]. Available: http://doi.acm.org/10.1145/1226969.1226998

[21] S. Delle Monache, D. Rocchesso, and S. Papetti, “Sketch a scratch,” in *Eight International Conference on Tangible, Embedded and Embodied Interaction, Work in progress*, ser. TEI '14, 2014.