The Sound of Touch: Physical Manipulation of Digital Sound

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ABSTRACT
The Sound of Touch is a new tool for real-time capture and sensitive physical stimulation of sound samples using digital convolution. Our hand-held wand can be used to (1) record sound, then (2) play back the recording by brushing, scraping, striking or otherwise physically manipulating the wand against physical objects. During playback, the recorded sound is continuously filtered by the acoustic interaction of the wand and the material being touched. The Sound of Touch enables a physical and continuous sculpting of sound that is typical of acoustic musical instruments and interactions with natural objects and materials, but not available in GUI-based tools or most electronic music instruments. This paper reports the design of the system and observations of thousands of users interacting with it in an exhibition format. Preliminary user feedback suggests future applications to foley, professional sound design, and musical performance.

ACM Classification Keywords
H.5.2. [Information Interfaces]: User Interfaces—*interaction styles; input devices and strategies; auditory feedback; haptic i/o*. H.5.5. [Information Interfaces]: Sound and Music Computing—*methodologies and techniques; systems; signal analysis, synthesis, and processing*.

Author Keywords
sound design, tangible user interface, materials, sensing, digital convolution.

INTRODUCTION
Manipulating digital sound samples is a common activity in music, film, and home media production. Today's digital waveform editing software is functionally powerful, yet its GUI-based interface fails to utilize the lifetime of experience that people have making sounds with physical objects and materials. For instance, we know what it will sound like to scrape a pencil against a pillow, or what a coffee mug will

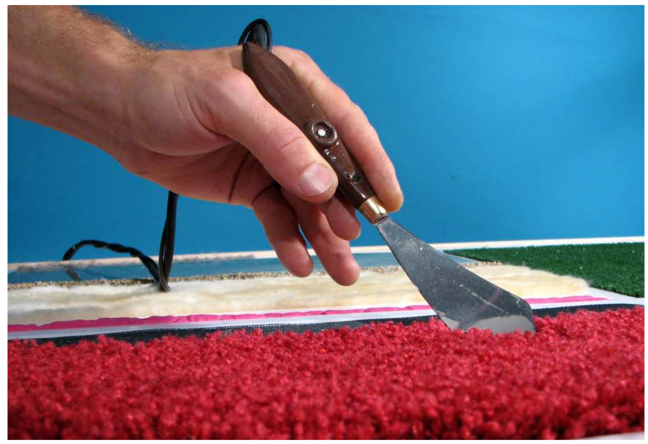

Figure 1. The Painting Knife tool is scraped against shag carpet, convolving a digital audio sample with the acoustics of the carpet's physical texture.

sound like if tapped against a glass window. This experiential knowledge guides us when we create sound with objects in our environment and underlies the development of acoustic musical instruments, but does not typically contribute to our manipulation of digital sounds.

The Sound of Touch is an instrument for real-time capture and sensitive physical stimulation of sound samples using digital convolution. The system takes the form of a handheld 'wand' that contains an embedded microphone, piezo vibration sensor, and pushbutton. When a user presses the button, the system begins recording, and captures a digital sound sample as long as the button is held. The user can then stimulate this sound by brushing, scraping, striking or otherwise physically manipulating the wand against real-world objects. During this playback, the recorded sound is continuously filtered by the acoustics of the interaction between the wand and the material being touched. Different surfaces each provide a unique character to the recorded sound. Texture palettes provide a wide range of physical materials, enabling users to experience the acoustic implications of a variety of surfaces that are normally perceived by sight and touch. Stored sound and texture are thus combined in a way that transforms the perception of each medium.

This system enables a continuous and physical sculpting of sound that is typical of interactions with natural objects and materials, but that is not available in GUI-based tools or most electronic music instruments. The Sound of Touch makes our lifetime of experience with the sounds of *physical* materials relevant in the manipulation of *digital* sound samples. In this paper we discuss design development of the system and report on the observations of thousands of people who used The Sound of Touch in an exhibition format.

THE SOUND OF TOUCH SYSTEM

We adapt Aimi's methods [1] for realtime percussion instruments, which allow a stored digital sound sample to be 'stimulated' continuously by the signal from a piezoelectric vibration sensor attached to a drum brush. Aimi's work develops a number of 'semi-acoustic' percussion instruments that convolve pre-recorded samples with the signal from piezoelectric sensors manipulated in real-time, to provide greater realism and intuitiveness to digital percussion. The underlying mechanism of this stimulation is a continuously running digital convolution of the stored sound sample and the digitized incoming signal from the piezoelectric element.

Digital Convolution

The digital convolution algorithm is fundamental to much of modern digital signal processing (DSP) [6]. The basic principle of digital convolution is similar to mathematical correlation: by multiplying sections of the two signals together sample-by-sample at each time step, then summing and scaling the result, a new signal is created that contains the frequency content in common to both of the two original signals. If a snippet of a congressional speech is *convolved* with a sample of a church bell being struck, the resulting audio will have the character of both original sounds, as if the speech were being played *through the church bell* or vice versa. In the Sound of Touch, every nuance of the physical contact between the wand and a texture elicits sound that incorporates the common frequencies of the physical interaction and the recorded audio sample. For example, if a user records the word 'hello,' tapping the wand against a piece of felt produces the 'hello' as if it were recorded through felt.

User Interface Advance

While digital convolution creates acoustically rich cross filtering of two audio samples, traditional methods of using the algorithm are abstracted (typically via graphical waveform editors) and do not promote users' experimentation and improvisation convolving a variety of audio samples. The Sound of Touch is a new interface that puts convolution into a user's hands quite literally: a low-latency ($<$ 20 ms) convolution algorithm [2] is paired with an acoustically-sensitive tangible interface (wand). The physicality of the wand and textures makes manipulating digital sounds with the Sound of Touch akin to manipulating ordinary physical objects, but the system allows a user to work with a larger variety of sounds than physical objects alone would permit.

Our interaction design is inspired by work in Tangible Interfaces such as IO Brush [7], which presents a single brush-like tool with embedded video camera to record and then manipulate a visual recording on a computer display. With IO Brush, users paint with 'digital ink,' whereas with the Sound of Touch users are painting with sound. Additionally, a great deal of work has been done to develop novel interfaces to sculpt digital audio in musical ways, e.g. the literature of the International Conference on New Interfaces for Musical Expression (NIME), and some of it aims to leverage users' experience with physical objects and/or haptics to inform their expressive manipulation of sound or music [5]. It is noteworthy that The Sound of Touch sidesteps the common and often central challenge [3] of designing an effective mapping from sensor input to synthesizer parameters with its direct convolution of two user-created acoustic signals.

Wands

The wand is a multi-purpose tool, affording both sound recording and manipulation. We built four distinct wands for the system, each with different materials for the handle and tip, and found that these materials greatly impacted the user experience and expressive potential of the instrument. All the wands featured a pushbutton to initiate recording, an electret microphone to capture sound, and a piezo element to sense the vibrations induced from contact with physical objects and textures.

Brass Blade

This first prototype wand [4] employed a wooden dowel handle, and the tip was made from thin brass, cut to resemble a painting knife. A flat disc piezo sensor was affixed directly to the blade with epoxy, and a button was taped to the handle.

From this wand we learned two important lessons. The first was that rigid, disc-style piezo sensors capture a relatively limited frequency range, which reduced the sonic potential of this wand. Experiments with flexible piezo sensors showed a much greater range of frequency sensitivity, and they were used in all successive designs with good results. Second, the flexibility of the Brass Blade allowed it to 'kink' to a degree that could cause undesirable sonic artifacts. As a result, stiffer materials were used for subsequent wands.

Drum Brush

A flexible piezo sensor was fitted into the end of the rubber housing of a drummer's steel brush. The sensor was positioned such that its end would rest against the base of the bristles, sensing their movements and vibrations.

The Drum Brush's numerous steel bristles caused its effective surface area for sensing to be large compared to the Brass Blade. This was sometimes an advantage when scraping the brush against uniform textures like stone tiles or fur, since many points of parallel contact with the surface created a rich, dense chorusing effect. However, this high contact density became problematic when trying to hear the effect of a particular surface feature, such as individual aquarium pebbles or slats of a wooden window-blind. The effect of the brush's bristles themselves became the dominant acoustic impression, obscuring these surface patterns and making many of the textures produce very similar effects. In response to this observation, we built two follow-up wands that featured single stiff blades.

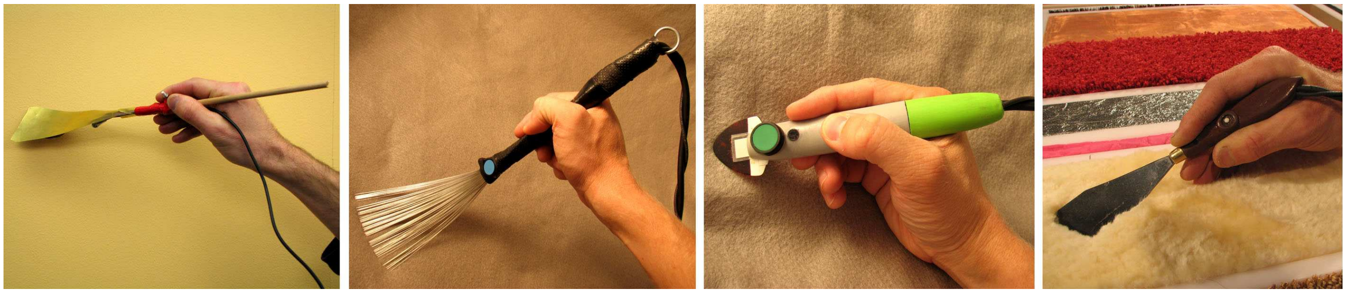

Figure 2. The four wands that were created for The Sound of Touch. From left to right they are the Brass Blade (too flimsy), the Drum Brush (good for uniform textures, but everything sounds similar), the Plastic Wand (good control, but absorbs too much vibration) and the Painting Knife (best).

Plastic Wand

We instrumented the body of a felt-tip permanent marker, with a nylon guitar pick mounted in a slot cut into its tip. The marker's body provided a handle that was lightweight and appropriately sized for a typical user's hand. The guitar pick was pliable, but durable enough to survive many repeated flexes. The flexible piezo sensor was laminated directly to the guitar pick with tape.

The Plastic Wand's single tip proved to be more satisfying than the Drum Brush for exploring textures. Acoustic characteristics of different textures were more perceptible when the Plastic Wand scraped across them, and its fine edge allowed for more precise sonic exploration of surface features. However, the all-plastic body had the feel of a toy. Furthermore, the flexibility of the body and the tip, and the pliable coupling between them resulted in an absorption of higher frequencies, making the sound from this tool more muffled than the metal-tipped wands.

Painting Knife

A microphone, pushbutton, and wiring were embedded directly into the wooden handle of a carbon steel painter's knife (see Figure 1). The piezo sensor is laminated to the knife under a layer of durable metallic tape.

The Painting Knife proved to be the most versatile wand. Like the Plastic Wand, its single tip makes it better for articulately exploring a wide range of textures. However, the stiffer steel and wooden handle allow vibrations to propagate to the sensor with less absorption into the tool itself. The result is a richer, more full-spectrum sound. Finally, the Painting Knife feels more substantial than the Plastic Wand, giving it the feel of a serious, high-quality tool.

Textures

The record-and-playback wands of the Sound of Touch are paired with a diverse set of textures upon which to 'sculpt' live-recorded or pre-recorded sounds, affording a great range of sonic possibilities. A recorded digital sample can be stimulated in extremely diverse ways depending on the tool, the texture, and how the two are used together.

For a recent exhibition we designed two 'texture kits': flat, free-standing tables that measured approximately 1x1 meters. The surface of each table was divided into a series of rectangular regions, with a different material in each. In order to leverage users' lifetime of experience hearing the sounds of physical objects, we sought to offer a wide range of materials that were acoustically and texturally diverse, yet familiar. These included hard uniform bathroom tile, sheep's wool, broom bristles with varying stiffness, artificial turf, aquarium pebbles, shag carpeting, metal screen, and wicker curtain pieces. The patterns of holes in the tables were modeled after paintings by Piet Mondrian, for aesthetic interest.

INSTALLATION AND FEEDBACK

The current Sound of Touch system was installed in a high-traffic area of an international computer graphics and interaction conference in August 2007, where it was used by thousands of visitors over the course of five days. Two texture tables featured different spatial layouts of similar textures. One table featured our record-and-play wand, which allowed for the exploration of sounds created by the user. This setup allowed for quick 'sketching' in sound, where a user would record a new sound, experiment with the various textures for a minute or two, then record a new sound and iterate. The other table had two wands that each allowed certain pre-selected samples to be loaded using buttons mounted in the table. The available pre-selected sounds were mostly percussive in nature, ranging from cymbal crashes to a piano impulse response, to a 'laser gun' sample.

Observations

During the installation we observed many different styles of use. One axis of variation was the degree to which people used the wands as percussive versus 'sculpting' instruments. At one end, some users played with the system as if it were an electronic drum kit, striking the wand sharply against the textures. In this mode of use, the surface features of the textures were not as important as their overall density and pliability. This style of use was more common at the table featuring pre-selected samples. Even though the convolution algorithm was identical on both tables, it is likely that our choice of percussion oriented samples contributed to this usage pattern. Other users made very slight, deliberate scraping and brushing gestures, sensitively exploring the sonic variations that came from the fine details of the materials' surfaces. In both classes many users seemed determined to try every texture, leading them to methodically work their way across the entire table.

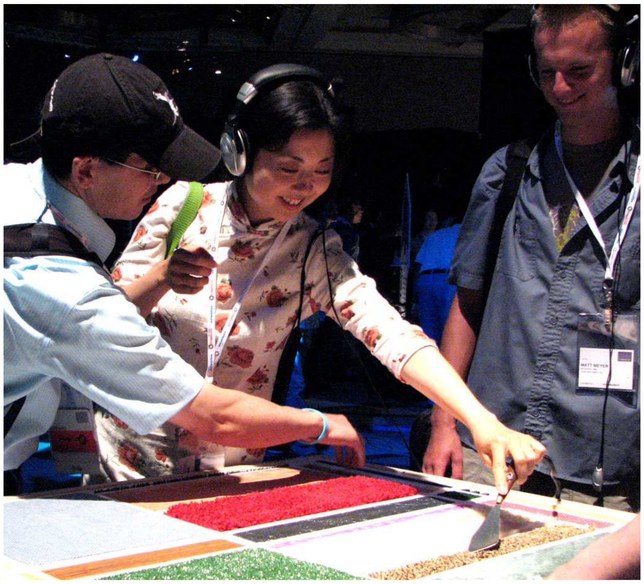

Figure 3. Visitors using our recent installation of The Sound of Touch system. The woman in the center is using the Painting Knife tool.

Some visitors noticed that different size scales of surface features provided interesting variation in granularity. For instance, one mosaic-like tile arrangement contained a repeating pattern of large and small tiles. When a wand is moved across this pattern, it produces a repeating rhythmic tempo. This large-scale low-frequency periodicity contrasts with the tiny high-frequency *stick-and-slip* vibrations possible across a sandblasted slab of marble when the knife scrapes the material quickly at a glancing angle.

Findings

Musicians and sound engineers were particularly interested in the Sound of Touch. Musicians reported that they would like to use it in performance settings, particularly in improvisational ones. They were intrigued by the question of how one would write notation for the system, and how the spatial layout of the textures might be reconfigured to support different compositions or playing styles. The record-and-playback table was most appealing to those with experimental interests, while those with more traditional tendencies - particularly percussionists - liked the table with pre-selected samples.

Sound engineers and foley artists[1] reported that the Sound of Touch could be a new way for them to create sound effects and adapt them to different contexts. The possibilities that The Sound of Touch offers for real-time exploration and quick iteration on ideas could allow them to get more use from their vast and under-utilized libraries of samples, or to manipulate synthesized or newly recorded digital sounds in more intuitive ways. We were told that the record-and-playback wand could be useful for quick sketching and exploration of sonic ideas, while the table featuring pre-selected sounds might be used for final renderings.

[1] A *foley artist* inserts sound effects into a movie or television program - such as footsteps, keys, squeaky hinges, gunshots, etc.

CONCLUSIONS AND FUTURE WORK

Four iterations of wand design, and a subsequent public installation that featured two tabletop texture kits has demonstrated that the Sound of Touch is an intuitive instrument for a variety of users to quickly and iteratively record and manipulate digital sounds. Many users suggested applications to foley, professional sound design, and musical performance. Our continuing research addresses how users will employ the system as a tool for professional work and live performance. A musical composition class at MIT recently used the system to expand the sonic timbres of sounds that they synthesized using digital techniques, and we are also collaborating with musicians who will use the Sound of Touch for improvisation.

During the course of the five-day exhibition each wand required repair 1-2 times, so in the future we will increase the durability of the tool. We are also investigating how to make the Sound of Touch system more portable, so that sounds and textures encountered in a user's everyday life can be easily appropriated as source material for the system. The most open-ended opportunity for future work is that we currently have no way to create larger compositional structures for musical purposes. In order for a single player to perform a complex musical piece or to improvise with a group, the Sound of Touch would need an ability to sustain or layer multiple sounds, to retain a palette of sound samples to select from, and to start and stop them quickly. We will investigate these features and other functionality that may be required for musicians and sound designers to incorporate the Sound of Touch into their work.

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