A Spatially Distributed Vibrotactile Actuator Array for the Fingertips

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ABSTRACT

The design of a Spatially Distributed Vibrotactile Actuator Array (SDVAA) for the fingertips is presented. It provides high-fidelity vibrotactile stimulation at the audio sampling rate. Prior works are discussed, and the system is demonstrated using two music compositions by the authors.

Author Keywords

Vibrotactile, assistive devices, sensory augmentation

CCS Concepts

•**Applied computing** → **Sound and music computing;** •**Hardware** → *Haptic devices;* •**Social and professional topics** → Assistive technologies;

1. INTRODUCTION

1.1 Vibrotactile Feedback for Music

A number of projects have previously considered ways in which vibrotactile feedback can be used in music applications. In the early 2000s, Gunter and O'Modhrain suggested some ways to apply sound design techniques in the domain of vibrotactile signal synthesis. They called this *tactile composition*, and it was aimed toward audience members who were wearing full-body suits with integrated vibrotactile actuators [5].

A series of vibrotactile chairs have also been designed for music applications. Both the Model Human Cochlea [6] and the Haptic Chair [9] had eight actuators or fewer. The Sense chair incorporated more actuators, but most of these were low-fidelity ultrasonic actuators, which do not work well at low frequencies where human perception is more precise [7]. The Auris chair incorporated a slightly larger number of actuators, but the actuators placed at the wrist were low-fidelity eccentric rotating mass (ERM) motors [2].

Vibrotactile signal processing has also been applied to the design of vibrotactile digital musical instruments, such as investigated by Birnbaum for a flute-like digital instrument [3] and others.

1.2 Emphasis on the Hands

The authors are interested in haptic feedback for the hands. One reason for this is that the hands are particularly sensitive to the perception of tactile stimuli. The fingertips in particular have a low threshold for vibrotactile perception [8]. One prior project appears to have delivered vibrotactile feedback for five fingers; however, beyond news articles, no academic publications have reported on the project results [11].

We are presently focusing on delivering vibrotactile feedback to all ten fingertips. This is achieved using a Spatially Distributed Vibrotactile Actuator Array (SDVAA). The SDVAA is shown in Figure 2, which hosts ten vibrotactile transducers. Each one is separately controllable at the audio sampling rate, which enables the system to operate with high fidelity. The configuration of the transducers is arranged to correspond with the curve and spacing of the fingers and thumb in a relaxed state.

The remainder of the SDVAA includes ten channels of DA conversion via USB audio interface and amplification, all housed in a single enclosure. As a standalone unit, the ten-channel design of the SDVAA can be driven with signals designed specifically for vibrotactile sensation, constructed in conjunction with music composition but processed and delivered separately from audio content, as discussed further below.

2. PRELIMINARY TECHNICAL RESULTS

The fidelity of the system seems to be quite good compared to an earlier prototype made using linear resonant actuators (LRAs). This system, based on the Tectonic TEAX19C01-8 19mm Metal Cup Exciter from Parts Express, has sufficient power and can operate in high-fidelity over a large frequency range. Further results relating to signal processing for the SDVAA remain in development and will be reported upon at a future date. The current results will be presented via the presentation of two different music compositions, each of which can serve as its own demonstration of the system.

3. DEMONSTRATIONS

3.1 Fingerpickin'

Fingerpickin' is an etude written by the first author for inaudible, vibrotactile stimuli only. It was created through the recording of audio signals from a hexaphonic guitar pickup, which had a separate piezo sensor for each string. The string signals were then pitch-shifted down by two octaves in order to enhance the touch sensation. Finally, the signals were low-pass filtered with 18 dB/octave filters in order to help make the sound of the SDVAA less audible. Specifically, the cutoff frequencies 190 Hz, 140 Hz, 105 Hz, 90 Hz, 66 Hz, and 50 Hz were used.

The etude is called *Fingerpickin'* for two reasons. First, some of the material used in creating it was generated by making fingerpicking gestures on the guitar. Also, the SDVAA itself effectively "picks" the fingers of the person who is using the it to experience the composition.

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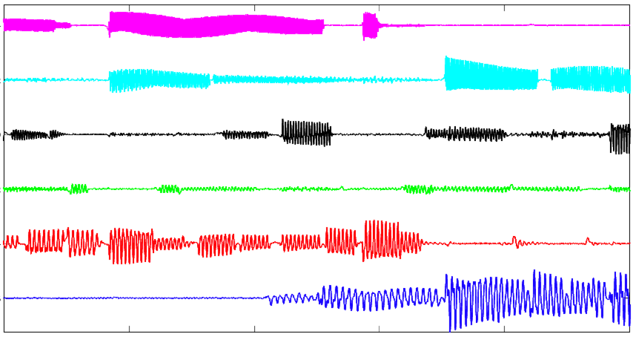

Figure 1: Excerpt of the six channels of stimuli from a recording of *Fingerpickin'*, which stimulates six fingers using the SDVAA.

This composition questions what it means to practice purely *tactile composition* and to what degree such a composition can be considered a music composition without audio, since the principles of music composition are employed while organizing the material.

3.2 Tactus

Tactus, by the second author, is a composition that is made using a Digital Audio Workstation (DAW). It was realized as follows: First, an aggregate device was created combining the audio interface from the SDVAA with the headphone output of a laptop. Then, music was composed through arrangement of sound clips in the DAW. The music tracks were routed to the laptop headphone output for playback. Concurrently, the vibrotactile presentation was designed by duplicating audio clips in parallel on additional tracks, which were routed to the SDVAA.

Signal processing was applied to the vibrotactile signals in order to enhance the tactile sensation. Audio clips were pitch-shifted downward by one or more octaves in order to better match the frequency response of the clips to the vibrotactile senses. For example, while the human range of hearing spans 20 Hz-20,000 Hz [4], tactile perception functions predominantly in the range from 0 Hz to as high as 1-2 kHz, with particular fingertip sensitivity beneath 250Hz [8]. It was decided to shift by an integer number of octaves (rather than semitones in addition to octaves) due to the apparent ability of humans to crossmodally perceive notes across octaves [1].

In most cases, a lowpass filter was also applied to each vibrotactile clip. For instance, the lowpass filter characteristics tended to remove vibrations at frequencies above the tactile threshold of perception. Different lowpass filters were applied to other clips in order to organize the stimuli as desired.

The title of the work is in reference to both the takt (e.g. underlying musical pulse [10]) and the tactile sensory system. Rhythm lies at the intersection between these two faculties, and thus it is used as a main structural element. The source materials were gathered from digital waveguide strings in Pd. This patch produced quasi-granular textures, that when time-stretched in a DAW, yielded unexpected and surprising sounds.

Figure 2: A person feeling ten channels of vibrotactile stimuli from the SDVAA.

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