The Touch Flute: Exploring roles of vibrotactile feedback in music performance

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***Abstract*— Research in haptic perception strongly suggests that many parameters of listening carry over to vibrotactile feeling, such as sensitivity threshold, range, and the just noticeable difference in the context of both amplitude and frequency. But to what extent does a musician rely on the natural vibration feedback provided by acoustic instruments to monitor and modify the ongoing performance? This paper describes a device called the Touch Flute, constructed with the ability to arbitrarily control these parameters, and a series of experiments are proposed as potential uses for the device.**

I. INTRODUCTION

Within the closed loop of music performance, control data is passed from the performer to a sound generating device, and feedback is returned back to the performer in the forms of visual, auditory, and haptic information. This feedback can be considered in two contexts [10]:

- *primary / secondary* - where primary includes kinesthetic and tactile feedback, visual feedback, and the sound of the functional attributes of the interface, and secondary refers to the sound produced by the instrument.
- *passive / active* - where passive refers to that which the physical design of the system provides, such as the shape and feel of the interface, and active refers to feedback produced by the system itself in response to user input, such as the sound produced by an instrument.

Derived from the Greek word for touch, the term *haptic* can apply to any system in which touch plays a role [2]. A computer keyboard is therefore an example of a haptic device because it displays information to the user through touch. The standard keyboard features a small surface anomaly (usually a raised dot or a bar) on specific keys, displaying to the user the location of her fingers in a sea of otherwise indistinguishable discrete positions. This is clearly an example of passive feedback, as the display is a characteristic of the keyboard's physical construction and cannot be arbitrarily modified. Active haptic devices employ actuator components to provide feedback varying in intensity, frequency, location, velocity, or otherwise, and are controlled by a software program. The haptic sense is comprised of two modalities [4]:

- *kinesthetic / proprioceptive perception* - the innate awareness of body posture and limb position, and the sensation of forces against the body.
- *tactile sensation or taction* - sensation of pressure, temperature, texture, surface shape, orientation, puncture, wetness, slip, adhesion and vibration.

This paper is concerned with the tactile mode - whether musicians derive useful information about their performance from instrument vibrations, and how to incorporate vibrations into gestural interfaces. We will define *gesture* as performer actions produced by the instrumentalist during a performance, and *digital musical instrument (DMI)* as an instrument having a gestural interface that is separate from its sound generation unit [10].

Parameters of Vibrotactile Perception

The first question to ask when designing a touch display system is, what are the boundaries of useful information? Amplitudes and frequencies must be bounded within the range of sensitivity. Also, certain bands may provide heightened sensitivity, in which case we wish to display more vital and/or subtle information in these ranges.

The tactile sense is made up of the sum of four separate mechanoreceptors that react differently to stimulation, and therefore relay different tactile parameters. The four types of receptors are typically catagorized in terms of their rate of adaptation, physical location inside the skin organ, range of sensitivity, and the type of information they transmit [4]. The characteristics of the tactile sense discussed here are the combined result of these four receptors acting together.

The absolute threshold of detection is dependent on the frequency of the stimulus, and the size of skin area to which the vibration is applied [8]. Sensitivity begins to increase above 40 Hz, and peaks at about 250 Hz, meaning a combination of lower intensity and smaller contact size are necessary to perceive vibration near this frequency. Sensitivity decreases dramatically as frequency increases above 250 Hz, and perception in frequency changes becomes impossible near 1000 Hz, though sub-harmonics may still be perceived. Note that the peak frequency of 250 Hz is just below middle C on a piano keyboard. The frequency response of most acoustic instruments covers the range of tactile sensation and more, dipping to a minimum of about 40 Hz but extending well above 1000Hz. Frequency discrimination has been found to range anywhere from 3 to 5 distinct values between 2 and 300 Hz [9], to 8 to 10 values between 70 and 1000 Hz [7]. About 55 dB above the threshold of detection, vibrations may become unpleasant or painful [4]. The just noticeable difference in frequency has been variously reported to be as much as 30% or as little as 3%, and is smaller at low frequencies but grows with frequency. It is interesting to note that [8] also describes a qualitative difference in tactile perception between frequencies below and above 100 Hz; lower vibrations are more often described as a 'buzzing' sensation, while higher frequencies as a 'smooth', non-localized sensation. Phenomenon of *enhancement*, *suppression*, *summation*, and *masking* (loosely tied to their psychoacoustic counterparts with similar nomenclature) present themselves when two stimuli are applied to the skin. If separated by a short time interval, one may cause the other to be perceived as more or less prominent. When two vibrations are applied at the same time in different locations on the skin, one stimulus with higher amplitude may cause another to not be perceived at all. Prolonged exposure to tactile stimulation can result in *adaptation,* a perceived decrease in vibration intensity [4]. Tactile sensitivity to waveform is many magnitudes less sophisticated than hearing, where much of the aesthetic quality of music is comprised of timbre. Instead, waveform can only be perceived according to the amount of harmonic content, ranging from sine waves described as 'smooth' or 'glassy' and square waves as presenting a 'rougher' feeling. However the use of 'warble tones' (or AM modulated tones) has been shown to increase ability to perceive frequency changes, especially in the upper range [8].

Vibration levels present on the surfaces of acoustic instruments are often well above the threshold of detection, but it is unclear if musicians make use of this information. The vibrations in the neck and fingerboard of a violin do not significantly contribute to the sound output, but may be responsible for the 'feel' of one violin as compared with another. Performers certainly report that the vibration of their instrument creates a feeling of response and presence. Such is the contention of one of today's leading violin soloists, who only plays in clothing that leaves the shoulders bare so that she may feel the violin vibrating against her skin [1].

II. METHODOLOGY

The Touch Flute was constructed to facilitate experiments to determine the usefulness of vibration information to performers. It provides a gestural control interface, and both audio and vibrotactile feedback.

Control Input

The Touch Flute is based on an acoustic woodwind instrument; the system is excited with breath pressure, and the frequency of output is modified by the position of finger-controlled keys. As a research tool, it is not intended for musical performance and so it was not required to produce the full range of key combinations the typical wind instrument offers - the Touch Flute features only two keys. However, the force-response of pressing a key, known to instrument designers as the *action*, was particularly important since the focus of the device is to accurately represent the haptic qualities of a typical woodwind instrument. Keys were removed from an existing clarinet and attached to a plastic cylindrical body. Inside the body, a hall-effect sensor was placed under each key to sense its binary position. (No additional magnet was placed on the keys themselves because the key actuators have magnetic properties that suffice to activate the sensors beneath.) A straw in the mouthpiece directs breath into an air pressure sensor, the Fujikura XFPN-25 [11]. While this method of breath pressure sensing is precise and reliable, it is not truly an analog of an acoustic woodwind excitation system, because no air is allowed to pass through the instrument. The sensor measures air pressure rather than air jet speed, and the feeling of exhalation that is experienced by woodwind players is not preserved. Indeed, a minimal amount of air is expelled from the lungs even at high pressure levels.

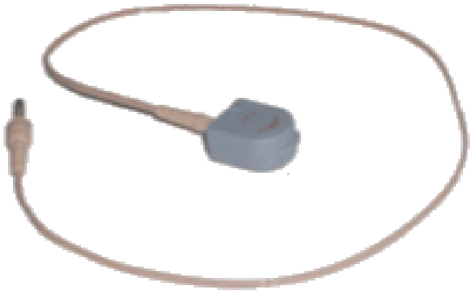

Fig. 1. The Skin Stimulator from Tactaid

Haptic Display

Two types of actuators are typically employed in active vibrotactile systems - unbalanced motors (or *vibration motors*), whereby a mass load is added to the drive shaft, and voice coils. Motors were the more immediately attractive choice because they are capable of higher amplitudes of vibration. However, to effectively drive a DC motor at variable frequencies requires either a voltage rectifier, if using AC, or pulse width modulation, if driving the motor with DC. Furthermore, vibration motors are heavier and bulkier than voice coils, and have a much less accurate transient response, a particularly crucial quality for this application. Voice coils, on the other hand, are ideal for variable frequency operation and precise transient response, as they are used for acoustic reproduction. They are also commonly employed as tactile aids for speech training, speechreading, and acoustic information for physically disabled persons. In fact, no signal conditioning is required to drive a voice coil actuator from a standard audio output, except possibly amplification.

Placement of the actuators is consistent with research stating that there is a high density of mechanoreceptors in the fingerpad and the embouchure, causing them to be more sensitive to vibration [4]. While there is certainly some sensation in the torso of a saxophone player who holds her instrument close to her body, the overwhelming amount of haptic information is conveyed through the receptors in direct contact with the keys and the mouthpiece. A small actuator was placed on each key to provide feeback through the fingertips, and a larger one integrated into the mouthpiece. The voice coil was removed from earbud headphones for the keys, and a small mass added to the cone to increase the amplitude of low frequency oscillations. For the mouthpiece, the Skin Stimulator by Tactaid [3] was used. This lightweight voice coil device is manufactured as a speech aid, and has a 250Hz nominal peak output to match the peak of human sensitivity.

III. IMPLEMENTATION

The auditory feedback synthesis utilized the *clar˜* object from the Percolate physical modeling object library [5]. *clar˜* is a physical model of a clarinet, fitting nicely with the visual metaphor of the Touch Flute. Amplitude was controlled with breath pressure and frequency determined by one of the four possible key positions. These same control parameters were mapped to the haptic output. However a *cycle˜* object was used in this case because it requires much less computing per sample, and sensitivity to the difference between a sine wave and a physical model of a woodwind is negligible. A 2-channel D/A converter was used; one channel for the actuators via a microphone cable, the other for a pair of headphones worn by the performer. In order to increase the dramatic effect of the haptic feedback, a small battery-powered amplifier was placed inside the body of the instrument. A switch to turn the amplifier off provides the option of using the device as a traditional wind controller.

IV. ANALYSIS

Reactions

No formal experiments have been performed with the Touch Flute, though there has been consistency in the qualitative descriptions of the effectiveness of the device. The sensation from the embouchure actuator was said to overpower that of the fingertips, likely because of the larger skin area exposed to vibration. Performers were highly susceptible to adaptation effects, as they reported the intensity of the haptic experience abruptly declined after approximately 20 seconds of playing, though it quickly returned after a short break. The fact that the haptic feedback could be eliminated with the flick of a switch allowed for quick comparison. Most interesting was a perceived improvement in the natural behavior of the instrument with the feedback turned on. Players describe their experience as being more connected to the music, and when switched off, feel the instrument is ’cold’ or ’distant’. This gives rise to the possibility that trained woodwind players would prefer a device that provided vibrotactile feedback because they feel more comfortable or familiar with it, certainly leading to a qualitative improvement of performances with wind controller-based DMIs.

Uses

The Touch Flute will allow for experimental testing of musicians’ reaction to variability in the parameters of vibrotactile feedback as compared against simultaneous auditory feedback. A recording could be made with the player being given sound feedback alone, tactile feedback alone, and both together, and the recordings compared to determine which types of feedback the player utilizes to influence a performance. The effect of unexpected or impossible vibration parameters corresponding to the audio feedback, such as inverting the frequency response, could be observed. In a large scale study, compositions could be played with varying levels of vibration intensity and frequency accuracy, to see which parameters of vibrotactile feedback deserve the most attention when designing a new system. The Touch Flute employs only one channel of vibrotactile information, but by adding separate channels for each actuator, a wealth of new information could be displayed to the performer. Information about the synthesis parameters and patch settings could be potentially be communicated discreetly during performance according to location, frequency, and amplitude of vibration. The perceptual phenomena of masking, enhancement, summation, and suppression could also be explored. The aural effect known as ’beating’ occurs when two slightly differently frequencies stimulate each ear, and their difference is perceived as a separate frequency. This effect might well exist between fingerpads whose actuators are changing phase. With a multichannel haptic interface, this possibility could be investigated.

Fig. 2. The Touch Flute

V. CONCLUSION

The Touch Flute is an important first step in creating a versatile wind controller-based DMI with feedback resembling the experience of playing an acoustic instrument. Issues such as methods of actuation, haptic feedback signal synthesis and amplification, and its correspondence to auditory feedback were addressed. For vibrotactile feedback in a musical context, voice coils are preferable to vibration motors because they are being used, in essence, to simulate an acoustic event. Users reported an improved feeling of ’warmth’ or ’familiarity’ with the instrument when vibrations were present, indicating players of traditional woodwind instruments might prefer vibration feedback in wind controllers for increased realism while playing. Further experimentation will determine the extent to which vibration feedback is used by performers. Dividing the signal into several channels displayed at different locations could test the viability of utilizing multichannel vibrotactile feedback.

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