Vibrotactile Feedback in Digital Musical Instruments

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ABSTRACT

This paper discusses vibrotactile feedback in digital musical instruments. It compares the availability of intrinsic vibrotactile feedback in traditional acoustic musical instruments with the lack of vibrotactile feedback in most digital musical instruments. A short description of human sensory ability with regard to this form of feedback is given and the usefullness of vibrotactile feedback to musical performers is also briefly discussed. A number of devices are examined which can be used to provide vibrotactile feedback in a digital musical instruments and some experiments to evaluate these devices are also described. Finally, examples are given of a number of instruments which make use of some of these devices to provide vibrotactile feedback to the performer.

Keywords

Digital musical instruments, tactile feedback, vibro-tactile feedback

1. INTRODUCTION

Most traditional musical instruments inherently convey an element of tactile feedback to the performer in addition to their auditory and visual feedback. Reed instruments produce vibrations which are felt in the performer's mouth, string instruments vibrations are felt through the fingers on the strings, or through contact between the performer's body and the resonating body of the instrument [3]. This tactile feedback leads to a tight performer-instrument relationship which is not often found in digital musical instruments.

Studies have shown that while beginners make extensive use of the visual feedback provided by musical instruments, in expert performance it is the tactile and kinaesthetic which is the most important [7]. The majority of digital musical instruments provide only auditory and visual feedback to the performer, which results in a less complete sense of the instrument's response to the player's gestures than is available with traditional instruments [3]. It has also been stated that only the physical feedback from an instrument is fast enough to allow a performer to successfully control articulation [11].

This paper begins by discussing how we sense vibration in traditional musical instruments and goes on to discuss how the vibrations of a traditional instrument can be simulated in a digital musical instrument to enhance the "feel" of the instrument which results from these vibrations in acoustic instruments [6].

2. TACTILE FEEDBACK

Tactile (or vibrotactile) feedback results from contact between the body of the performer and the vibrating body of the musical instrument. Mechanoreceptors in the skin are sensitive to these vibrations. The fingers are capable of sensing vibrations in the region of 40 Hz to 1000 Hz and are most sensitive at 250 Hz [15]. These frequencies are within the audible range and are also frequencies which are among those produced by acoustic instruments.

As these vibrations are created by the resonating elements of the musical instrument in a traditional instrument and a digital musical instrument may not contain any resonating elements it is necessary to simulate the vibrations in order to provide some form of tactile feedback to the performer. In order to best simulate the vibrations of an acoustic instrument, the method used to provide vibrotactile feedback in a digital musical instrument should be variable in both frequency and amplitude and should be directly related to the sound the instrument is producing [13]. These leads to certain requirements for such a device which are different from the requirements of system which use vibrotactile feedback for information communication, which often use amplitude or location of vibrations as indicators and are generally fixed in frequency (for example [5] and [8]). These requirements are:

- Wide range of requency repoduction (at least 40–1000Hz)
- Control of amplitude of vibration
- Fast transient response
- Easy to control from a synthesis system (i.e. controlled using a signal rather than a complex protocol)

3. DEVICES FOR VIBROTACTILE FEEDBACK

A number of different types of devices are available to produce vibro-tactile feedback in digital musical instruments. These include:

- Tactors
- Piezo-electric elements
- Voice coils
- Motors
- Solenoids

3.1 Tactors

A tactor is a device containing small plates which can be moved electrically to create vibrations. A tactor was used in experiments in adding tactile feedback to the LaserBass [2], but was found to offer too low an amplitude of vibration and to have a small delay when driven, which made it unsuitable for a vibrotactile element of a digital musical instrument. Tactors are commonly used to convey information to users in simulations and interfaces for the blind [17] or tactile information systems [5].

3.2 Piezo-electric elements

Piezo-electric elements are crystal elements which vibrate when an electrical current is applied to them. Normally used as sound producing devices in low-cost buzzers, they can also be used as vibro-tactile transducers. They do not seem to have found use as vibro-tactile sound producers in digital musical instruments, but have been used in other tactile displays, such as the Optacon system for tactile representation of text [9]. Other tactile interfaces have tried to use piezo-electric elements, but found the sound generated to be too loud for their requirements [5].

3.3 Voice coils

Voice coils are coils held in the field of an electromagnet which vibrate when an AC current is applies to the electromagnet. Voice coils have been used to provide tactile feedback in a number of digital musical instruments, including [3], [12] and [1]. As they can be driven using the same audio signal as that creating the audio output of the instrument they are easily used as vibro-tactile devices in digital musical instruments.

3.4 Motors

Miniature motors can be made to rotate at different speeds, which combined with an unbalanced shaft can cause vibration. They are commonly used as vibrational alarms in pagers and mobile phones and can also be found in many vibrotactile game controllers.

3.5 Solenoids

Solenoids have pins which are forced in and out of the solenoid body by applying a DC voltage and can be used to produce vibrations. The Tactile Ring [2], which contains a miniature solenoid has been succefully used to add tactile feedback to a number of instruments, including the LaserBass and the SonoGlove.

4. EVALUATING DEVICES FOR VIBROTACTILE FEEDBACK

In order to evaluate which of these devices might be suitable for use in providing vibro-tactile feedback in digital musical instruments, a series of experiments were run. These experiments attempted to determine the range of amplitudes of vibration which each device could generate, the range of frequencies of these vibrations and the transient response of the devices when attempting to move from one frequency to another and one amplitude to another. This would allow us to see which of the devices are capable of meeting our requirements. All the devices used (with the exception of the tactor) were off the shelf components, which were not specifically designed for use as vibrotactile feedback devices.

4.1 Methodology

In order to accurately measure the amplitude and frequency of the vibration of each of the devices an apparatus was built making use of a 2-dimensional accelerometer mounted to a small board. This board was placed in contact with the active area of each device and so vibrated with the devices. The accelerometer produces two voltages, which are proportional to the acceleration in each of the devices two axes. These voltages, along with the input signal being sent to each device (either a varying DC voltage, a varying frequency sine wave or a pulse width modulation (PWM) signal) were logged using a National Instruments DAQ and Labview 2.1 software, operating at a sampling frequency of 10 kHz. The logged data was then analysed using GNU Octave.

The data logged allowed for the analysis of a number of aspects of each of the devices. The ability of each device to output frequencies in the 40Hz to 1000Hz range was tested, along with the maximum amplitude of vibration the device could create for frequencies in this range. This gives a measure of the usefulness of the device for creating vibrations at the frequencies which are felt through the fingers. Next, the range of amplitudes which each device can create was measured for a series of frequencies in this band, giving a measure of the amplitude control available with each device. Finally, the transient response of each device was tested for changes in frequency of 100Hz, 200Hz and 500Hz.

4.2 Results

Table 1 indicates the results found for each device during the testing along with some other important characteristics of typical devices of each type. As can be seen from the table, all of the devices are capable of reproducing the necessary frequencies of vibration (although many tactors display a peak in the frequency response at 250Hz, the frequency of vibration to which the skin is most sensitive). The motor and the solenoid display worse transient responses than the other devices. Examining the amplitude response of the three audio signal-driven devices shows that the voice coil and the tactor typically give the largest range of vibration and the voice coil can also produce the strongest vibration of all of the devices.

Another item of note is that the tactor's are generally capable of lower amplitudes than the other devices, perhaps making them more suited to applications where they will be mounted in direct contact with the skin, rather than through another surface. Also of interest is that the amplitude and frequency output of the motor are inherently linked and that many solenoids are incapable of changing the amplitude of vibration.

Simulating the vibration of an acoustic instrument requires the ability to reproduce a range of vibration frequencies. While performers may not be able to accurately discriminate between a large number of frequencies, some ability to distinguish gross frequency cahnges does exist. In fact, the ability to distinguish between different frequencies has been shown to range anywhere from between 3 to 5 distinct values between 2 and 300Hz [12] to 8 to 10

Table 1: Comparison of results for each device

	Tactor	Motor	Solenoid	Piezo-electric element	Voice coil
Frequency response (over tactile range)	40–1000Hz (peak at 250 Hz)	40-1000Hz	40–1000Hz	40–1000Hz	40–1000Hz
Maximum amplitude	low	high	high	high	high
Amplitude range	good	good	single value	good	good
Amplitude and Frequency Control	independant	dependant	only frequency	independant	independant
Transient response	good	poor	good	excellent	excellent
Driving signal	Audio signal	PWM signal	PWM signal	Audio signal	Audio signal
Typical size	3cm dia., 0.7cm height	0.6cm dia., 1.5cm length	1.5 cm dia., 2cm length	2.5cm dia., 0.3cm height	from 1cm dia. up to 20cm dia.
Availability	uncommon (from manufacturer)	common	common	common	common
Typical Price	US$60	US$3	US$5	US$2	US$2 – US$100

distinct values between 70 and 1000Hz [16]. A qualitative difference has also been found in tactile perception of frequencies above and below 100Hz, with a different sensation being reported for frequencies in each range [16].

This would seem to indicate that for a vibro-tactile feedback system in a digital musical instrument the ability to reproduce a range of frequencies is important and so a device capable of this might be most suitable for providing this feedback. The tactor, the piezo-electric element and the voice coil devices can cover the frequency range. The voice coil offers a greater amplitude range and maximum amplitude output, but along with the piezo element, will also generate sound, which the tactor will not do.

5. USING VIBROTACTILE FEEDBACK IN DIGITAL MUSICAL INSTRUMENTS

A number of instruments and controllers have been built which make use of vibrotactile feedback to improve the interaction between the performer and the system. Chafe used a voice coil to simulate vibrations in the mouthpiece to help players control a physically-modelled brass instrument [3]. The VR/TX system [12] made use of vibrotactile feedback to augment a glove-based non-contact system, again using voice-coils. Bongers [2] discusses a number of systems which were augmented with a Tactile Ring, which uses a miniature solenoid to provide tactile feedback to the performers.

Each of these systems made use of vibrotactile feedback to the performer, in many cases providing this feedback through an audio-driven device. With some of these, as with many other tactile feedback systems, attempts were made to cover the audio output from the device, so that it would not be heard by the performer. The following sections detail a number of instruments which have been developed to include vibrotactile feedback, which make use of voice coils to provide this feedback, but rather than attempting to quiet the devices instead make use of this sound output to provide both vibrotactile and audio feedback to the performer. The aim is to produce an instrument which has a "feel" most like that of an acoustic instrument [2], by integrating the sound production into the instrument, giving vibrotactile feedback which is directly related to the sound being produced [13] and producing a sound output which is local to the instrument rather than being created at another point by a speaker system.

5.1 The Viblotar

Figure 1 shows the Viblotar[1] [10]. It is an instrument designed to be played in a similar fashion to a traditional monochord and can be played on the performers lap or on a table or stand. The synthesis engine for this system consists of a physical model running in the Max/MSP environment. The model comes from the PeRColate [14] externals which is a port to Max/MSP of instruments from the Synthesis ToolKit (STK) [4] [2]. The physical model used is a hybrid model called the *blotar* which is a hybrid of an electric guitar model and a flute model.

Figure 1: The Viblotar

The Viblotar is played using the right hand to both select and excite pitches. It has a range of 3 octaves of continuous pitch, which are played using a linear position sensor. Excitation is caused by the pressure of the hand which is selecting the pitches. This allows for dynamic control of both pitch and amplitude using a single gesture. Two pressure sensors are also available to the left hand, to allow for pitch bend and vibrato effects.

The audio and tactile feedback to the performer is created using a pair of small 1W BTL amplifier circuits to drive a pair of 8 Ω 3W speakers. The body of the Viblotar functions as a resonating box and has been designed to maximize the frequency output of the speakers, from the determined small signal parameters of the speakers. As the audio output from the synthesis engine is used to drive these speakers, both the audio and vibrotactile feedback to the player are directly related to the sound being produced and so create a more tightly coupled interaction between the performer and the system.

[1] http://www.music.mcgill.ca/~marshall/projects/viblotar
[2] http://ccrma.stanford.edu/software/stk/

5.2 The Vibloslide

The Vibloslide is a small electronic wind instrument. It is a monophonic instrument, but unlike many wind instruments it is played using a continous position sensor rather than discrete keys or holes. This allows it to produce any pitch over an octave range and to produce effects such as glissando's which are not available with many wind instruments. A small piezo-electric film element is mounted at one end of the tube and is used to detect air being blown into the tube, to control the excitation and dynamics of the sound. Overall, this allows for a performance technique similar to a traditional slide whistle. Figure 2 shows the Vibloslide.

Figure 2: The Vibloslide

Again, in order to give tactile feedback to the performer, a small speaker is mounted at the far end of the tube. This is driven by the synthesis system through another small 1W BTL audio amplifier. The generation of the sound output therefor occurs at the instrument itself and the resulting vibrations in the instrument body can be felt by the performer through the fingers and the lips. This results in a similar feeling to the Touch Flute [1], which use a number of small voice-coil actuators to produce tactile feedback, but with only a single actuator to provide the vibration and the addition of integrated sound production.

5.3 Discussion

While a number of instruments have been developed which incorporate vibrotactile feedback and many of these instruments have made use of voice coils to generate this vibration, not many seem to have also used the voice coils to generate sound from the instrument. The addition of one or more small speakers and amplifiers to a digital musical instrument can provide the benefit of both integrated sonic and vibrotactile feedback and lead to a tighter performer-instrument interaction loop. However, as the sound quality of many small speakers and amplifiers is quite poor, an means of connecting the sound output from the synthesis system to external amplifiers and speakers is also necessary to allow for maximum sound quality.

The two instruments described here each make use of speakers in this way. People who have played these instruments comment on the feeling of a "complete" instrument rather than a controller. As expected the addition of vibrotactile feedback and sound production in the instruments give a "feel" which is more like that of a traditional instrument and less like a computer interface.

6. CONCLUSIONS

This paper discussed vibrotactile feedback in digital musical instruments. It compared the vibrotactile feedback available in traditional acoustic musical instruments with the lack of this feedback in many digital musical instruments. A number of devices which could be used to simulate the vibration of an acoustic instrument were instroduced and compared. Finally two instruments were introduced which have been developed and which make use of integrated audio speakers to produce both audio and vibrotactile feedback for the performer. This additional feedback to the performer would seem to improve the "feel" of the instrument, so that it is associated more with being an instrument rather than a computer controller.

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