Audio Engineering Society
Convention Paper
Presented at the 128th Convention
2010 May 22–25 London, UK

Tactile Music Instrument Recognition for Audio Mixers

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ABSTRACT

To use touch screens for digital audio workstations, particularly audio mixing consoles, is not very common today. One reason is the ease of use and the intuitive tactile feedback that hardware faders, knobs and buttons provide. Adding tactile feedback to touch screens will largely improve usability. In addition touch screens can reproduce innovative extra tactile information. This paper investigates several design parameters for the generation of tactile feedback. The results indicate that music instruments can be distinguished if tactile feedback is rendered from the audio signal. This helps to improve recognition of an audio signal source that is assigned e.g. to a specific mixing channel. Applying this knowledge, the use of touch screens in audio applications becomes more intuitive.

1. INTRODUCTION

The use of touch screens for digital audio workstations, particularly audio mixing consoles, is not very common today. One reason is the intuitive tactile feedback that hardware faders, turning knobs and buttons provide (see Figure 1). Digital audio workstations are mainly operated using hardware control surfaces or keyboard and mouse.

A touch screen is a multi-functional device that can be easily configured to the users needs. A lot of new interactive possibilities arise. Adding well designed tactile feedback will make the touch-sensitive screen an interesting alternative human interface device. To reproduce the tactile feedback of traditional equipment (like simulating a push button using a touch screen) is one straight forward approach (for a literature review see [1]).

Alternatively, the tactile channel might be used to provide additional information. One example is to improve recognition of an instrument or microphone

Fig. 1: Traditional faders on a mixing desk give intuitive tactile feedback.

that is assigned to a specific mixing channel. Unless labeled correctly, the sound engineer can not see this connection directly. Is the bass drum or the hi-hat connected to the channel of the touch screen fader that I'm touching at the moment?

Especially modern touch screen controllers with adaptable interface configurations allow closely spaced control elements. Thus the ability to give visual feedback reduces (see Figure 2).

To solve this problem, the authors propose to reproduce a vibration signal at the fingertip of the user, while touching e.g. a fader or a button. The vibration signal needs to refer to the specific audio signal source connected to the current channel. This paper investigates, if an audio engineer can identify such a meaning in an intuitive way. Several design parameters for the generation of the audio driven tactile feedback are studied.

To generate tactile feedback from audio signals, it is essential to understand the capabilities and limitations of the auditory and the tactile sense.

2. AUDITORY PERCEPTION

The perception of sound is a complex area that has been studied for several decades. The basic physical attributes of sound (e.g. intensity, frequency or location of a sound source) have been correlated to perceptual attributes like loudness, pitch or distance. Different effects like adaptation to loud signals or masking characterize the auditory system. However, there is much more complex processing before a listener assigns meaning to a perceived sound. Integration with other senses and the experience of the user plays an important role. All those factors should be taken into account when audio driven tactile feedback is rendered. However, this paper focuses on the basic frequency perception and intensity perception of the auditory and tactile sensory systems.

2.1. Frequency Perception

The lowest frequency at which sound is perceived as a tone is around 16 Hz. For even lower frequencies it is possible to follow the time structure of a signal [2]. The perceived character of the sound changes

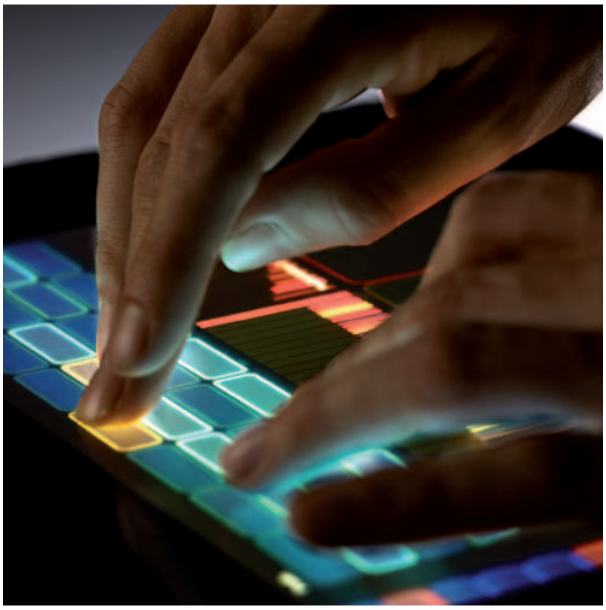
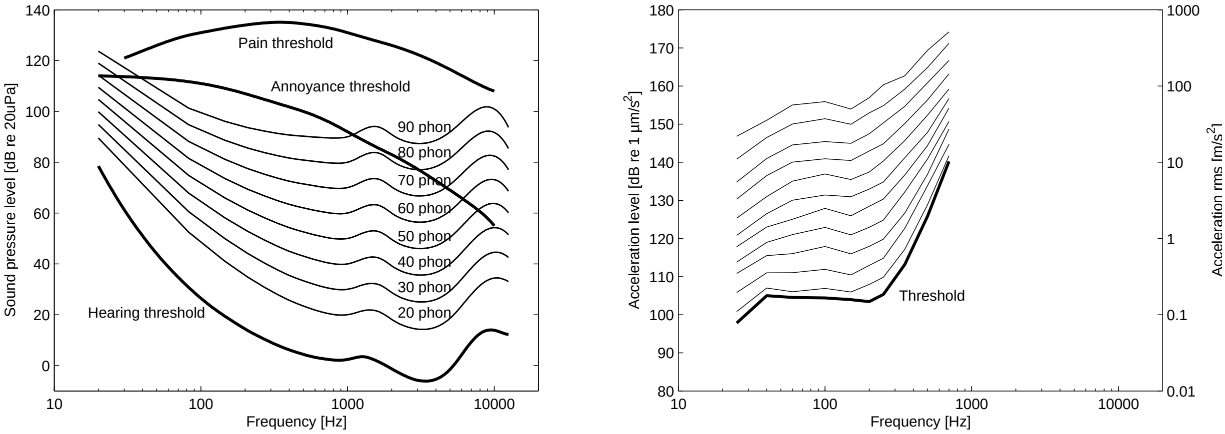


Fig. 2: Audio controller Lemur from JazzMutant (picture reproduced with permission from stantum). Touch sensitive interfaces might benefit from audio driven tactile feedback.



(a) **(b)**

Fig. 3: Curves of equal subjective intensity plotted as a function of frequency for **(a)** sounds (according to ISO 226:2003 [6] and Winckel [5]) and **(b)** vibrations on the thenar eminence (adapted from Verrillo [3]).

and pitch perception fades. The upper frequency limit is around 20 kHz. It depends strongly on the age of the subject. Music perception takes place in the frequency range up to approximately 10 kHz.

One of the fundamental characteristics of the auditory system is the ability to discriminate between different frequencies. Differences as small as 1 Hz can be perceived in the range from 400 to 2000 Hz. The Weber fraction ($\frac{\Delta f}{f}$) in this region is approximately 0.2% for tones with 40 dB above threshold according to [4]. For lower or higher frequencies the difference limen for frequency discrimination increases up to several percent.

2.2. Intensity Perception

Figure 3 a) shows that the hearing is most sensitive to sound pressure between 300 and 7000 Hz. It becomes less sensitive for decreasing and increasing frequency. In addition, the figure shows estimates for the pain threshold and the annoyance threshold after Winckel [5].

The curves of equal subjective intensity (equal loudness contours) are plotted according to ISO 226:2003 [6]. They follow the threshold curve to some degree. It can be seen that they get closer toward lower frequencies. The relevant dynamic range is thus frequency dependent from 50 dB to more than 100 dB.

On the other hand, the auditory system is able to discriminate intensity differences between 2 and 0.2 dB, depending on sound pressure level [8].

3. TACTILE PERCEPTION

3.1. Frequency Perception

In comparison the tactile sense is rather limited. Only frequencies between a few Hertz and approximately 1 kHz can be perceived via the mechanoreceptive system. It has been reported, that the quality of sensation changes with frequency [7].

The ability to discriminate between frequencies is also quite limited if compared to the auditory system. A Weber fraction ($\frac{\Delta f}{f}$) of about 20% to 50% was found by [9] for sinusoidal vibrations at the finger, depending on frequency. This is much lower than the frequency discrimination ability of the ear, especially for higher frequencies (e.g. approximately factor 10 for 50 Hz and factor 80 for 200 Hz).

However, Rothenberg [10] showed that auditory pitch and vibrotactile frequency can be associated by hearing subjects without training. This was tested for variations in voice fundamental frequency (intonation patterns with moderate to strong stress patterns) using a short sentence.

3.2. Intensity Perception

Similar to the ear, the vibration sensitivity of the skin depends on frequency. In addition, the sensitivity depends strongly on the size of the contact area [7]. With increased contactor size, perception threshold decreases for higher frequencies. For very low frequencies, no influence was found.

Figure 3 b) shows the frequency dependent perception threshold on the thenar eminence adapted from [3]. It can be seen that the glabrous skin becomes more sensitive to the acceleration of a surface with decreasing frequency. The curves of equal subjective intensity follow the threshold to some degree. Again a frequency dependence can be seen. The curves get a little bit closer toward higher frequencies. The dynamic range can thus be quantified between approximately 35 dB to 50 dB. Vibrations more than 55 dB above threshold become very unpleasant or painful. Because thresholds vary between subjects, the usable dynamic range is even smaller.

There is not much knowledge of vibrotactile intensity discrimination. The reported values in the literature range from 0.4 dB to 2.3 dB. See [7] for a review.

Many more factors, like time of exposure or multiple simultaneous stimuli, have an influence on frequency and intensity perception, but will not be discussed here.

3.3. Summary

It can be seen that the frequency range of the auditory and tactile sense overlap up to approximately 1 kHz. Still there are some differences in the perception. The limited ability of the skin to discriminate frequency differences is important if audio driven tactile feedback is generated. In addition, the different dynamic ranges of both modalities have to be adapted.

4. AUDIO DRIVEN TACTILE FEEDBACK

The goal is to design a tactile percept that helps to distinguish between different musical instruments. To achieve this aim, the frequency range and characteristics of musical sound sources will be discussed below.

Each single note, that is processed in our auditory system while listening to a piece of music, contains plenty of information. Loudness, pitch or tone color are time varying parameters that help us to identify a specific music instrument. Some instruments are unpitched (like a snare), but most excite pitch perception (like a piano or a tuned percussion instrument).

Each tone consists of a fundamental and different harmonics. The harmonics are integral multiples of the fundamental frequency. Of these harmonics, the intensity of each partial may vary with time. Individual instruments can be distinguished using the upper boundary of the spectrum of partials [11]. Since only low frequencies can be perceived via the tactile sense, this high frequency information does not help to distinguish between instruments, unless shifted toward lower frequencies. But there might be already enough information available at lower frequencies.

Figure 4 shows the ranges of fundamental frequencies for selected instruments and voices. It can be seen that the common musical scale reaches up to 4 kHz. Still many instruments have most of their fundamentals below 1 kHz. Remember that the tactile perception reaches up to approximately 1 kHz. If the acoustic signal is reproduced as vibration below 1 kHz, the melody and/or time structure of a tone sequence from a specific instrument might be recognizable.

One important fact is that the fundamental does not need to be the strongest component in the spectrum. Still, the auditory perception will recognize the fundamental as pitch, due to the harmonics. In the tactile domain, there are no known studies about "pitch" like perception for complex signals.

In addition to the harmonic spectrum, many instruments exhibit some starting transient, inharmonic components or a noise background which might occur below 1 kHz [11].

Instruments can produce a large dynamic range. However, the intensity of musical sounds will be modified during the recording and mixing process. Values from hearing to pain threshold are possible. Thus adaptation of the whole auditory and tactile dynamic range is necessary. Otherwise audible sounds might not be sensible or overexcite the finger.

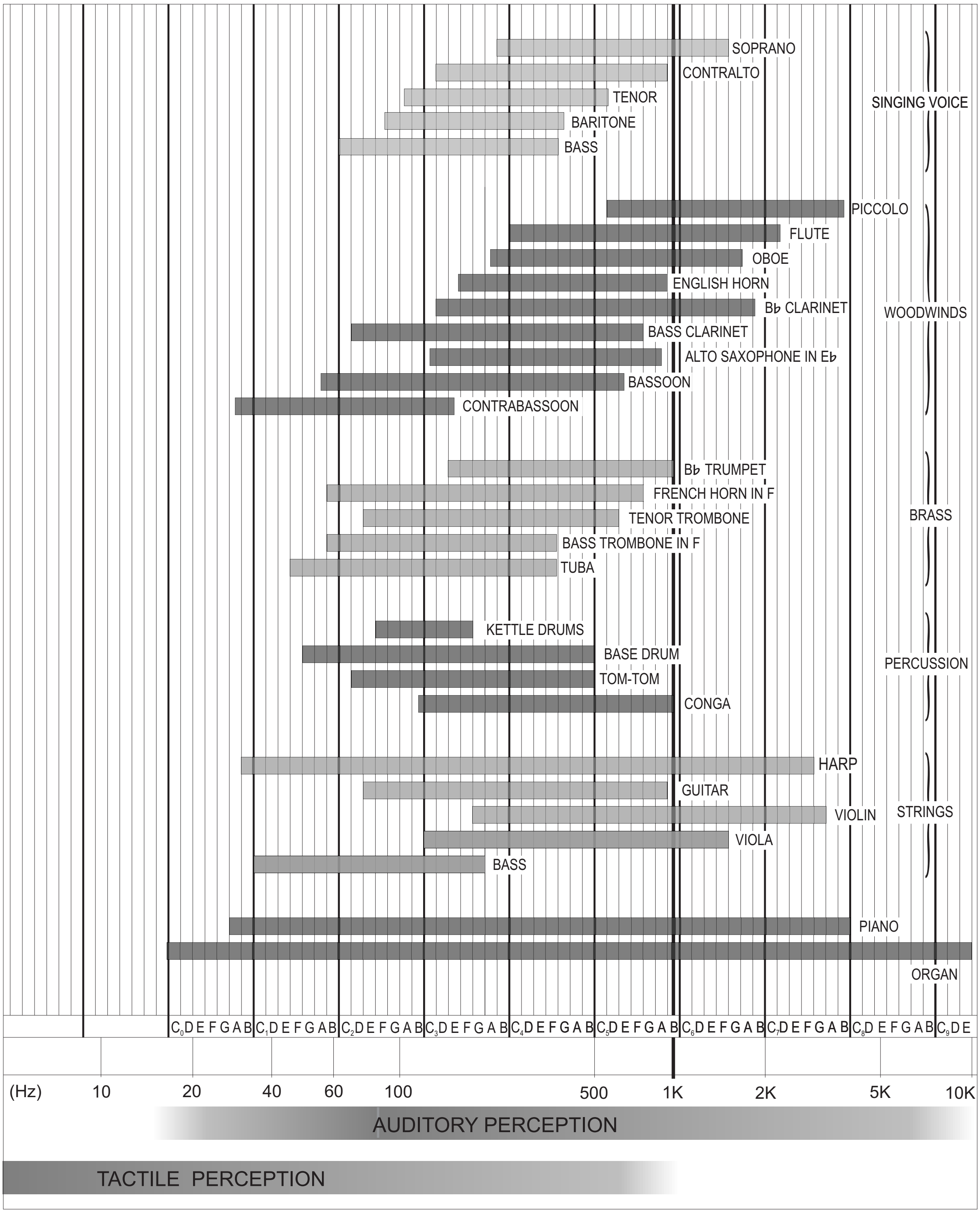


Fig. 4: Fundamental frequencies of instruments and voices adapted from [12]. The ranges for transients, noise, harmonics or partials are not indicated.

5. PILOT EXPERIMENT

The goal of this pilot study was to investigate if different music instruments can be distinguished if audio driven tactile feedback is rendered. For this purpose a typical live mixing situation was selected.

5.1. Setup and Stimuli

The setup can be seen in Figure 5. The mixer was implemented as a touch screen controller using Touch OSC for iPhone. The task of the subjects was to identify five different instrumental loops (bass, guitar, drums, piano, strings). The interface consisted of five volume faders and five "prefeel" push-buttons below. When the finger of the subject was in contact with a button or a slider, tactile feedback for the respective channel was rendered. This was done using an electro dynamic vibration actuator mounted below the iPhone. Only the audio signal of the active channel was used for generation of tactile feedback. Simultaneously the sum of all audio loops was played back over loudspeakers. Touching only the "prefeel" button, the user had the possibility to feel the vibration for a specific channel without changing the volume in the mix. Finger contact position was send to Pure Data running on a Mac via a Wi-Fi connection. To generate the tactile feedback, a low pass (10th order Butterworth) at 1 kHz was implemented. In addition the dynamic range was reduced, a frequency weighting was applied and the transfer function of the shaker was compensated. A schematic flow chart of the signal processing can be seen in Figure 6.

Six university students (5 male, 1 female; average age: 24) voluntarily participated in this pilot study.

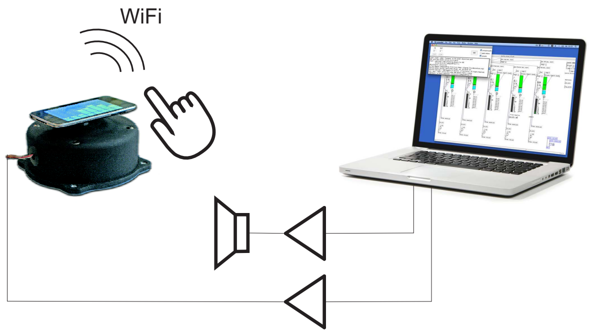


Fig. 5: Experimental setup.

5.2. Results and Discussion

The rendered feedback had no negative influence on the usability of the capacitive touch screen. Even for strong low frequency vibrations, smooth fading was unproblematic.

Subjects are two to three times faster to identify a specific instrument with audio feedback, than with additional tactile feedback.

With no tactile feedback subjects had to "prelisten" a specific track. Four subjects increased the volume using the fader until the instrument acoustically stood out from the mix. One subject reduced the volume to check which instrument disappeared.

With additional tactile feedback, subjects had the possibility to use the "prefeel" button. This was done by all subjects. Identification time was smaller for bass and drums than for guitar, piano and strings. It was reported that the bass line was felt as a smooth vibration and could easily be identified by following the pitch and the timing. The drums were felt like short hits. It was easily possible to distinguish between bass drum and snare because of their frequency content. Again the time structure played an important role for fast identification of the instrument.

The piano loop consisted of two components. One followed the base line at low frequencies and the other added some high frequency melody. This resulted in confusion with the bass itself. In addition it was reported that the low frequency content strongly masked the higher frequencies and thus dominated the tactile perception. This is consistent with findings from fundamental tactile research [7]. Similar masking questions arise for the use of multi touch interfaces.

Guitar and strings had more energy above 500 Hz. This resulted in a tingly tactile perception. Subjects were only able to separate both by paying attention to the time structure of the signal. Two subjects reported not to feel those high frequencies most of the time. This might be due to inter-individual deviations in the tactile perception threshold.

This findings indicate that some differentiation using low frequency cues is possible. However, the time structure of the signal played a more important role. Using the described approach might give good

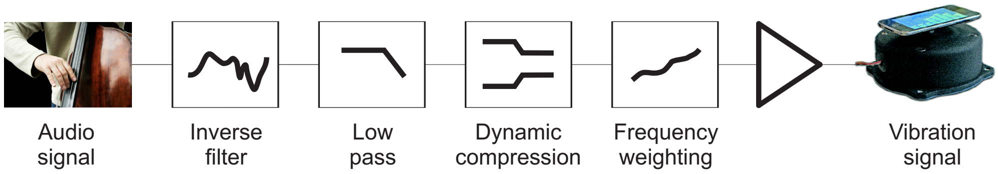


Fig. 6: Signal processing implemented in Pure Data for audio driven tactile feedback generation.

results for e.g. a drum loop machine with strong timing cues.

Earlier studies showed that there is often interaction between auditory and tactile perception. (E.g. vibration influences the perceived loudness [13] or quality of a sound [14].) In the audio mixing context there is always an audio signal present. The resulting multi-modal audio-tactile interaction has to be considered.

6. CONCLUSION

The results indicate that music instruments can be distinguished and recognized if audio driven tactile feedback is rendered in an appropriate way. Applying this knowledge, the use of touch screens in audio applications becomes more intuitive. Especially samplers, grooveboxes or drum machines might combine flexible interfaces with innovative and intuitive feedback. However, audio driven tactile feedback can also be used for traditional mixing hardware.

7. REFERENCES

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