TACTILE FEEDBACK BASED ON ACOUSTIC PRESSURE WAVES

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ABSTRACT

This paper describes a simple musical instrument utilizing acoustic radiation pressure waves as a force feedback method. The main idea that motivated the approach was rather utopian and envisioned an interface that would allow a musician to mould and shape some instance (abstraction) of a sound sound with his bare hands. While changing the shape of this - preferably immaterial - object the musician would experience its new shape and hear its acoustic appearance. A prototype instrument utilizing 97 ultrasonic transducers, one ultrasonic receiver and a mixing board was implemented for a very specific use - within the composition "Sonic beams / Acoustic shadows" utilizing a "no-input mixing board" audio aesthetics. The preliminary implementation of the interface, the tactile experiences and some concepts behind the composition "Sonic beams / Acoustic shadows" are discussed in the following chapters.

INTRODUCTION

An electronic musical instrument equipped with a tactile feedback section provides the musician not only with the audio- but also with a force feedback component resulting from its physical actions. Tactile feedback interfaces are found in the context of haptic musical instruments, which have been subject of research during the past decades. As (vibro)-tactile as well as force feedback is inherently present with most traditional acoustic musical instruments, the lack of this mechanical feedback in many electronic musical instruments has lead researchers to develop concepts to provide the (electronic) musician with more information about his playing in real-time. The concept is of a haptic musical instrument is very simply illustrated in figure 1. In (Marshall *et al.,* 2006) and (Berdahl *et al.,* 2008), the authors give a compact overview of mechanical devices, like: vibro-tactile actuators and force feedback systems, debate examples of hardware and software algorithms and further present a few example implementations. The interest of the present work however, lies within the context of non contact force feedback methods. Since 2001, researchers at the Department of Information Physics and Computing at the University of Tokyo have been investigating a non-contact method for producing tactile sensation using airborne ultrasound (Iwamoto *et al.* 2001). The result of their research is the recently developed tactile display for adding of tactile stimulation to hologram images (Iwamoto *et al.* 2008), (Hoshi *et al.* 2009). The concept of this tactile display consisting of an array of ultrasonic transducers was the starting point of the present research. The basic design from (Iwamoto *et al.* 2008) was altered and simplified in order to produce a compact and cost effective force feedback device.

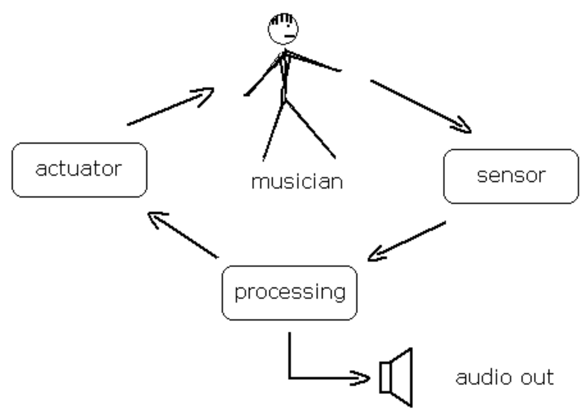
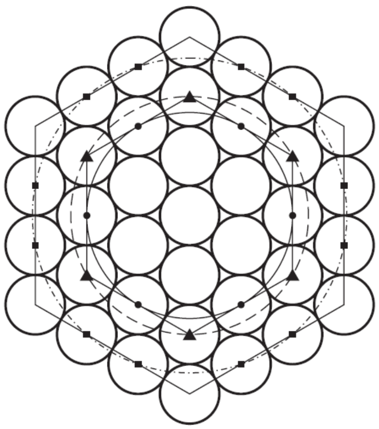


Figure 1. Haptic musical instrument.

AIRBORNE ULTRASOUND TACTILE DISPLAYS

The acoustic energy in ultrasonic sound is focused by nature. By combining several transducers into an array the strength of the tactile sensation can be increased and what is more, it enables the manipulation of radiation directivity. It is not possible to feel a constant ultrasonic radiation, instead, the tactile sensations occurs only at onset and offset of the ultrasonic signal. A tactile sensation of an audio signal can thus be achieved by modulating the amplitude of an ultrasonic carrier signal with the audio signal. Its beats, onsets and harmonic texture can be felt as a vibration of air, at a selected focal point. In (Iwamoto *et al.* 2008) the annular array of 91 hexagonal arranged airborne ultrasound transducers, was driven by a 12 channels amplifier circuit. By connecting all transducers that were equidistant from the array centre point, to one of the 12 channels (Figure 2), the acoustic radiation energy was focused by phase shifting the signal at individual channels, so that a focal point was created in an arbitrary distance along the centre axis, perpendicular to the transducers radiation surface. In (Hoshi *et al.* 2009) the display concept was extended, enabling even a 3 dimensional positioning of the focal point.



Fifure 2. electrical connection and arrangement of the transducers. Taken from (Iwamoto *et al.* 2008).

TECHNICAL SETUP

In the present work, there are 97 ultrasonic ceramic transducers of the type 400ST/R160 placed in an identical hexagonal arrangement as in (Iwamoto *et al.* 2008) - (Fig.2). The transducers operate at resonance frequency of 40kHz and – at the price of 2,7 EUR per piece – they are amongst the cheapest available ultrasonic transducers. One of the aims in this work was to achieve a low cost realization, which is a rather difficult task if we follow the phase-shift principles deployed in (Iwamoto *et al.* 2008) and (Hoshi *et al.* 2009). There is no conventional audio hardware that would be capable of producing precise phase differences at the frequency of 40kHz. Since there was no need for the device to to function as a 3D tactile display, it was decided to generate only one, spatially fixed focal point. For this purpose, it was convenient to mount the transducers onto a spherically shaped surface, focusing the acoustic radiation pressure at the sphere centre. In this constellation, all of the transducers could be driven by one single channel, since the required phase shifts for creating a focal point were achieved by spatial displacement of the sources (figure 3a). The reported results (haptic experiences) from (Iwamoto *et al.* 2008) and (Hoshi *et al.* 2009) were achieved at a 20- to 30cm distance from the transducers, therefore, it was decided that a sphere with a radius of 25cm was a good starting point for the experiment. Finding such a sphere turned out to be the most complicated task of the project, since its shell needed to be solid and non conductive. Eventually a city lighting company saved the project by donating an old park lamp shell made of 4 mm thick plastic. The transducers were then arranged on a small 320cm2 (round) piece of the lamp shell, which also held the them in place. The plastic shell was pierced through with the two connectors (phase and ground) of each transducer. On the other side, all the transducers were connected to into a parallel circuit, sharing the same phase and ground connection (figure 3b). The driving audio signal – a 40kHz sine wave carrier – was generated in Pure Data where also its amplitude was modulated by the audio signal that was to be displayed in a tactile way. The used audio interface was an "Edirol FA101" operating at 192kHz sampling rate. Further, the transducers are expecting a peak-to-peak driving voltage of up to 40 volts. The amplification of the audio interface output was achieved by an old Hi-Fi audio amplifier, which transmitted the 40kHz without difficulties and in an authentic / unbiased way. Since there are 97 transducers connected in parallel, they draw a lot of a lot of current, therefore some thick cables are needed for the connection to the amplifier.

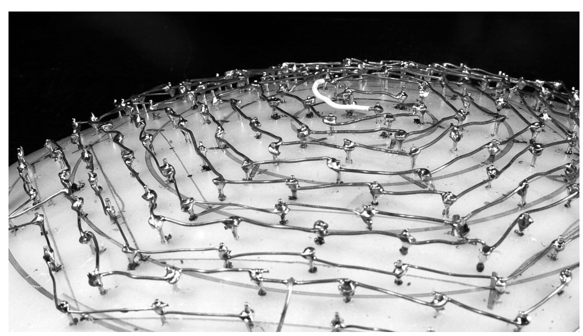


Figure 3. – Spherically arranged array of ultrasonic transducers – **a**: front side, **b**: rear side connections.

Feed forward concept

Until now only the tactile feedback concept was discussed, but since the device is meant to be an electronic instrument a "feed-forward" section is essential. The initial concept was to directly form the sound with ones hand. Now that we already have the tactile instance of the sound, a mechanism is needed to interpret hand movement and to establish a mapping from gestures to musical parameters. A straightforward solution would be to implement some video hand gesture analysis algorithms which is certainly going to be an interesting task for the future development of the interface. However, since the whole project was approached with a particular aesthetic motivation, which is found in many earlier works by the author e.g. (Ciglar 2006) where a "no input mixing board" is representing the central piece of the audio generation unit, also the feed forward concept was implemented in a related manner. A simple ultrasonic receiver was used – the same type: 400ST/R160 as the transducers – to pick-up the acoustic signals of the transducers and is placed in front of the array – 20cm behind the focal point. By moving his hand in the focal point region, the musician is acoustically shadowing the receiver. The incoming signal can thus be analysed for its its RMS amplitude value, which can further fe used for controlling the audio synthesis parameters. At this point however no digital analysis/synthesis was practically implemented but only a primitive analogue feedback experiment that will be discussed in the next chapter. Like the transducers, the receiver exhibits strong directivity characteristics and would only pick-up sounds projected directly in its direction. What is more, the receiver is extremely sensitive to its resonant frequency (40kHz) and is thus not reacting to the actual audible sound which is generated by the public-address system running in parallel. To increase the degrees of freedom in this method, one could simply add more receivers at different spatial locations, and generate complex data sets, simply by positioning its hand between the transmitters and the receivers.

COMPOSITIONAL ASPECTS

Like mentioned above, the audio generation is based on a no input mixing board concept. The primary feedback loops[1] generated with the mixing board are used as the modulating signal. A simple system configuration used in the referred composition is illustrated in figure 4. Within the context of the composition "Sonic beams / Acoustic shadows", the signal which is picked up by the ultrasonic receiver is fed directly into the input of the same mixing board. When the musician is playing the instrument, i.e. moving his hand around the focal point of the ultrasonic beam, he is indirectly manipulating the intensity of the receivers output. This signal, or better to say, the derivative of its RMS value is generating turbulences in the primary oscillation circuit of the mixing board. As a result a wide variety of acoustic material can be generated, merely by positioning ones hand between the transducers and the receiver.

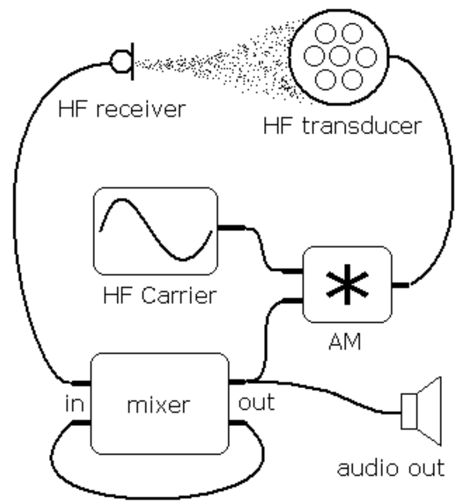


Figure 4. Technical set-up and connection of the of the tactile feedback interface with the sound generating device (the no-input mixing board).

In this set-up, the function of the primary feedback is also, to generate a signal that is actually audible. The HF feedback alone would not generate frequencies in the audible range.

Influencing Compositional Decisions

In previous compositional work of the author, i.e. (Ciglar 2006), (Ciglar 2008) the questions of influencing compositional decisions by alternative factors (i.e. other than the sound/music itself) – in particular, with a haptic instance of the sound – were at the centre of attention. Following the early body-conductivity concepts of electronic music pioneer Erkki Kurenniemi (Taanila 2005) and his instrument invention "DIMI-S" (the Sexophone), or, perhaps the most popular implementation of these concepts, disseminated with the CrackleBox instrument by Michel Waisvisz (Waisvisz 1970), the goal of the electronic feedback method in (Ciglar 2006) and (Ciglar 2008), was to apply the electronic instance of the sound immediately to the human body. The physical experience of the electronic current passing through the musicians body, was supposed to motivate the musician/composer to taking alternative compositional decisions, other than those, he would hold on to in a conventional performance

[1] In order to prevent terminological confusion it is important to mention that there are two sorts of feedback that are brought up in this paper. One is the haptic/tactile feedback, which is the central element of this work. The other form of feedback is an analogue electronic feedback, generated by a mixing board with its inputs connected directly with its outputs. This fed-back mixing board is used to generate the audio material in the referred composition "Sonic beams / Acoustic shadows". With the term "Primary feedback" I refer to the signal which is generated solely by one mixing board having its input directly (electronically) connected to its output.

situation, where his decisions on the choice of upcoming compositional elements were solely based on the acoustic aesthetics of the preceding compositional sequences. With the present, non-contact ultrasound force feedback method, the situation of-course is much more controllable, and no extremely unexpected reactions of the musician – like described in (Ciglar 2006) and (Ciglar 2008), where the strength of the electronic feedback could provoke uncontrollable muscle contractions – are likely to occur. Still, the concept remains the same, that is, to generate a compositional sequence, which is unlikely to occur, in a situation where the musician / composer wouldn't have had the possibility to experience this alternative (haptic) instance of the sound he is producing. Another parallel to playing an instrument by the direct connection of the musician and the electronic circuit of he instrument (i.e. CrackleBox (Waisvisz 1970)) can be found with the here proposed interfacing concept. Basically the situation where the musician is directly disturbing the transmission of a sonic beam with his hand could be interpreted in a very similar way as when the musician is changing the conductivity of an electronic instrument by the intervention of his (electronically conductive) body into the instruments circuitry. The ultrasonic transmitter-receiver section of the instrument can be seen as a short-time domain transformation (electronic → acoustic → electronic) of the instrument circuitry, enabling a different kind of intervention method and manipulation / feedback concept of the audio signal.

RESULTS AND CONCLUSION

The ambition behind behind this work was to develop a simple and cost efficient non-contact tactile feedback interface. All that is needed is a set of ultrasonic transducers (the more of them, the stronger the resulting tactile stimulus) a Hi-Fi amplifier and a conventional (2 channel) audio interface operating at a sampling rate of 192kHz. Perhaps, the same results could be achieved with a sampling rate of 96kHz, however, in this case, the 40kHz signal gets less accurate in frequency which might not address the full potential of the transducers radiation intensity. The tests that were made were very promising. It was actually possible to achieve a strong and spatio-temporally precise tactile reproduction of the projected audio signal. Unfortunately the laboratory at IRZU is not equipped with the adequate equipment to take accurate measurements of the "gram-force" values that were achieved. We can only speculate about the efficiency of this method compared with the phase-shift method applied in (Iwamoto *et al.* 2008) and (Hoshi *et al.* 2009), however, since in the present method, all the transducers are frontally oriented towards the focal point – meaning that the strongly focused acoustic energy produced by the ultrasonic signal, reaches the location of interest with its maximum amplitude – the solution with the spherically arranged transducers might even outperform the phase-shift method, in terms of force feedback strength.

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