Tuning Shapes and Bending Timbres — Experimenting with Smart Materials for Musical Purposes

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Premise

This publication reports on preliminary experiments in employing smart materials as central elements in a generative sound installation. For this installation, a material has been chosen whose piezoelectric properties can be altered by changing the material's shape. When integrated into a feedback loop, the material's capability to simultaneously act as an acoustic sensor and actuator establishes a sustained audio signal whose timbre is dependent on the bending of the material. By exploiting this material behaviour, a process can be set into motion within which the material serves both as tangible interface for interaction and as generative mechanism that drives the development of the musical output.

This work continues a research trajectory that explores the generative potential of physical processes and their integration into hybrid artworks in which physical and computational systems complement each other. Throughout the course of this research, the emphasis has increasingly been placed on the characteristics of physical processes while relegating the role of computation to one of control and stabilization. This installation demonstrates the potential usefulness of this approach but also highlights its pitfalls, the most important of which is the difficulty of controlling and scaling the complexity of a physical process through an incremental development method.

Keywords: Sound Installation, Smart Materials, Generative Music

1. Introduction

During the past years, the author of this article has been involved in the creation of generative artworks that integrate both computer-based and non-computer based elements. [1, 2, 3]. While doing so, the focus of this work has gradually shifted towards settings in which the predominant part of the artwork's functioning as a generative system is transferred into the non-computational domain while the role of the computer is relegated to one of control and stabilization. The work presented here expands on this research in that it employs smart materials as core elements of a generative system. In this particular case, a material has been selected that can function both as actuator and sensor for emitting and detecting acoustic waves, and whose capability to do so is dependant on the material's size and shape. The adoption of this material as a generative system is achieved by integrating both its acoustic sensing and emission functionality within a single surface. This can be used to give rise to a feedback loop through which an initial acoustic excitation becomes sustained. The sustained signal is then gradually transformed according to the particular characteristics of the material's mechanical and electrical properties. This publication reports on the results of characterizing the relationships between the material's size, shape, and acoustic properties. The author then demonstrates how these relationships, when being part of a feedback loop, shape the acoustic development of a self-sustained audio signal. Finally, the author presents a first attempt at translating these insights into the realisation of a generative audio installation.

2. Background

This background section contextualizes the current work with respect to theoretical and practical considerations in related artistic fields. Within generative art, this concerns the distinction between computer-based and non-computer based approaches. Within electronic music and particularly sound art, it concerns the increasingly prominent notion of "a materiality of sound" and its relationship to the properties of audio technology. Within media art, this concerns the interest in exploring smart materials as unconventional medium and as a method to closely connect the behaviour and appearance of an artwork.

2.1 Non-Computer based Generative Systems

Today, the vast majority of artists who realize generative artworks do so in the digital domain. This puts those artistic approaches within generative art that involve non-computer based systems into a minority position. This tendency fails to fully account for the conceptual foundations of generative art [4, 5]. As a result, many practitioners in the field are unaware of historical precedents in generative art and are also incapable of anticipating possible future forms of generative art [6]. For this reason, the contemporary artistic output mostly misses out on the large diversity of potentially promising generative approaches.

Nevertheless, several non-computer based generative artworks have achieved some visibility in the art domain. For reasons of brevity, only two of them are mentioned here. One of the possibly most famous examples is the "Condensation Cube" by Hans Haacke that has been realised in 1963. The cube consists of sealed acrylic that contains a small amount of water. Depending on the temperature and air currents present in the exhibition space, the enclosed water cycles through processes of evaporation and re-condensation, leaving ever changing patterns of streaks and droplets on the interior surface of the cube [7].

Another, more recent example is the work "Rule 30" that has been realised by Kristoffer Myskja in 2008. In this work, an electromechanical machine is punching holes into in a roll of paper. While doing so, the mechanism executes rule number 30 from the classical set of 256 one-dimensional cellular automata that have been systematically studied by Stephen Wolfram [8]. What is striking about this artwork is its capability to execute a computational process through non-computational means [5].

2.2 Materiality in Sound Art

An artistic movement that originated within the field of sound art is characterized by an altered stance towards the role of loudspeakers in an installation or performance setting. Conventionally, a loudspeaker is treated as a perfect and generic device that serves as a quasi transparent medium for transmitting sound. Contrary to this, the new movement places its creative focus on the establishment of a close relationship between the physical characteristics of a loudspeaker and the musical content that it emits. Consequently, the materiality of a loudspeaker is embraced, pushing its visual appearance, spatiality, and sound emission characteristics to the forefront of the compositional concern [9].

The notion of a set of loudspeakers as an orchestra of sonic objects was pioneered by David Tudor. According to Tudor, “the loudspeaker should have a voice which was unique and not just an instrument of reproduction, but as an instrument unto itself" [10]. Tudor has implemented this approach through different iterations of his piece “Rainforest” starting from 1965. The piece takes the form of concert-installations that consists of a collection of spatially distributed sculptural objects, each of them equipped with surface transducers and piezo-microphones, and each of them performed live [11].

A more recent example of a sonic object orchestra is represented by the “Shake-ousmonium” project that has been realized in 2015. Similar to “Rainforest”, the loudspeakers are custom designed by combining sound drivers with a range of materials. These loudspeakers serve as diverse and idiosyncratic sound sources for which different composers specifically wrote music for [9].

2.3 Smart Materials in Media Art

Smart materials are composites that possess one or more physical properties that change in response to external stimuli. These materials are capable of sensing external stimuli and actively responding to changes in these stimuli entirely on their own without the need for additional electronic or computational components [12]. While these materials have mainly attracted attention within engineering disciplines, there is a recent increase of interest within the HCI community, in particular among those working in the context of tangible computing. Here, the capability of smart materials to provide feedback to interaction other than through the visual or acoustic modality as well as the possibility of seamlessly integrating these materials into regular objects has opened up the possibility to envision entirely novel forms of interfaces and communication languages [13].

In his discussion of recent technologies that could have a significant impact on future, post-computer forms of generative art, Philippe Galanter identifies smart materials as one such candidate technology. These materials are fascinating for generative purposes in that they can assume multiple roles in an artwork. These roles include the material’s behaviour as an environment within which dynamic processes take place, as a medium for rendering these processes perceivable, and as an interface via which users can influence the material’s behaviour through tangible interaction. Accordingly, smart materials are capable of overcoming the divide between medium, process, and perceivable outcome that normally exists in the case of computer-based systems [5].

There exist several examples of artworks that employ smart materials. The two examples that are mentioned here are not particularly interesting from a generative point of view. Nevertheless, they shed some light on the artistic appeal of smart materials.

One example is the “Robotany” project that has been realised by Jill Coffin in 2008. In this project, the branches of a Japanese maple tree become capable of active movement by actuating them with shape memory alloy wire. Whenever a camera and an ultrasonic sensor array detect visitors walking nearby and interacting, the wires cause the branches to swing back and forth [14].

Another example is the “Magnetic Mind” project that has been realised by Lindsay Browder in 2013. This project exploits the property of fluids that contain nanoscale ferromagnetic particles to respond to an external magnetic field by changing shape. Here, the ferrrofluid acts as a kinetic sculpture that is controlled by brainwaves that are captured with a brain computer interface [15].

3. Implementation

The installation that has been developed in the context of this publication is depicted in figure 1. It is comprised of two piezoelectric films of different size, each of which is subdivided side by side into a region that operates as a loudspeaker and another region that operates as a microphone. Also depicted in figure 1 is a touch screen via which visitors can alter some of signal processing that is applied as part of acoustic feedback. The tangible manipulation of the shape of the piezoelectric films in combination with the graphical controls on the touch screen constitute the means for interaction with the installation. The installation also consists of two custom designed amplifiers (see figure 4), an audio interface[1], and a small PC[2], all of which are placed on the ground in front of the installation. The computer runs a simple, custom-developed digital signal processing application. The custom designed components will be described in more detail in the following sections.

Figure 1: Appearance of the Installation. Shown in this photograph are two piezoelectric films of different size that are suspended from a horizontal bar. Attached underneath the films is a touch screen that runs a simple graphical interface and that allows visitors to alter some aspects of the digital signal processing that forms part of the acoustic feedback.

3.1 Hardware

A schematic setup of all hardware components and their connectivity is shown in figure 2.

[1] Zoom UAC-2 USB audio interface
[2] Nuc7i5BNK mini computer

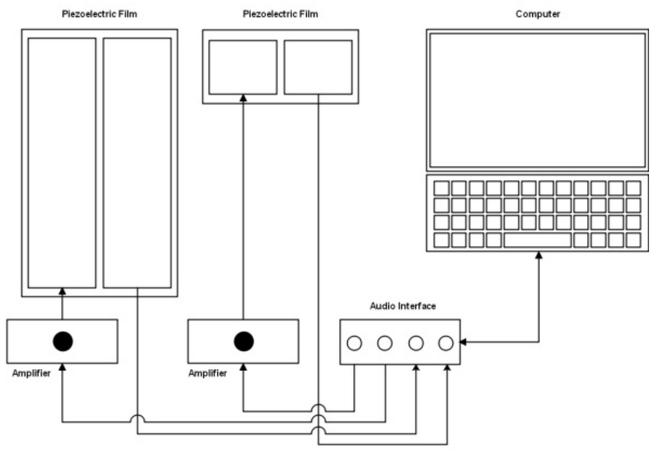

Figure 2: Schematic Depiction of the Hardware Setup. Shown are two piezoelectric films each of which contains a microphone and loudspeaker region, two audio amplifiers, an audio interface, and a computer. The audio amplifiers are connected to the audio interface and drive the speaker regions of each piezoelectric film. The microphone regions are directly connected to the audio interface. The audio interface is connected to a computer which runs a simple application for processing the audio signals.

3.1.1 Piezoelectric Film

At the core of the installation are two piezoelectric films that operate as loudspeakers and microphones and that are interconnected among each other in order to create acoustic feedback. The films are made from a composite material that consists of a membrane of Polyvinylidene fluoride (PVDF) that is coated on both sides with carbon nanotube layers. These layers are transparent and act as conductors [16]. The piezoelectric films are commercially available and are provided either as fully operational loudspeakers or as intermediate goods[3]. The latter product requires a little bit of handcrafting before it can be used as a loudspeaker or microphone. This includes cutting the film into its final shape, applying conductive ink[4] at the periphery and on both sides of the film, and glueing a copper tape[5] on both sides to a section of the ink. Electrical wiring running from and to other audio equipment can then be connected to the tape by means of alligator clips. All these components are visible in figure 1.

The basic principle by which the films are capable of sensing and emitting acoustic vibrations is based on the normal and reverse piezoelectric effect, respectively. A schematic depiction of these effects is shown in figure 3. In a nutshell, the normal piezoelectric effect is based on the ability of certain materials to generate an electrical charge in response to an applied mechanical strain. The reverse piezoelectric effect results from an applied electrical charge that produces a mechanical strain in the material.

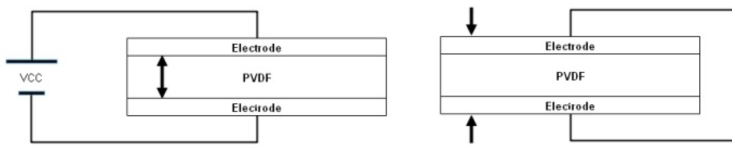

Figure 3: Schematic depiction of the piezoelectric effect. Shown on the left side is the normal piezoelectric effect in which a mechanical strain applied to a material generates an electric charge in response. Shown on the right is the reverse piezoelectric effect in which an electrical charge applied to a material results in a mechanical strain.

In order to exploit these two electromechanical effects for acoustic purposes, an external strain or an external electrical charge is applied in a periodic manner at a frequency within audible range of human hearing. In case of the normal piezoelectric effect, alternating sound pressure levels give raise to alternating strains in the piezoelectric

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3 http://film.koreasme.com/

4 Amepox Electon 45RT

5 3M 1181 X 1/2”

material which then translate into alternating electrical charges. Under these conditions, the material operates as a microphone. In case of the reverse piezoelectric effect, the application of a periodically alternating electrical charge is translated into alternating changes in the material's thickness which gives raise to alternating sound pressure levels. Under these conditions, the material operates as a loudspeaker.

By electrically separating different sections of the piezoelectric speaker films and by surrounding each of these sections with conductive ink, multiple acoustically distinct regions can be created within the same speaker film. These regions are still mechanically coupled through the film material but they can electrically operate separately from each other.

For the installation, two piezoelectric film sheets of different size have been prepared. One of the sheets is about 60 cm long and 30 cm wide, the other is about 15 cm long and 30 cm wide. Both these sheets have been subdivided into two regions that are identical in size and are placed side by side along the length of the sheet. This setup forms the basis to analyse the size and shape dependency of the acoustic properties of these sheets when operated as microphones or loudspeakers. In addition, the setup also permits to experiment with the creation of acoustic feedback that results from the mechanical coupling among loudspeaker and microphone regions that located on the same film sheet

3.1.2 Amplifier

The installation consists of two custom designed audio amplifiers. The necessity for a custom design arose from the requirement of the piezoelectric films to be driven at around 230 V which represents a much higher voltage level than regular amplifiers can provide. The seemingly simplest approach for realising a custom audio amplifier consists of combining a regular amplifier with a step-up transformer coil that increases the voltage output to the required level. The design of the custom amplifier follows this principle. The custom audio amplifier consists of the following components: a regular 60 Watt Mono amplifier board[6], a volume control knob[7], a toroidal transformer coil[8], a power regulation board, and sockets for electrical current, the input audio signal, and the amplified output audio signal. All these components are encased into a box made from acrylic. A photograph of a custom amplifier is shown in figure 4. A schematic depiction of the amplifier's components and their wiring is shown in figure 5.

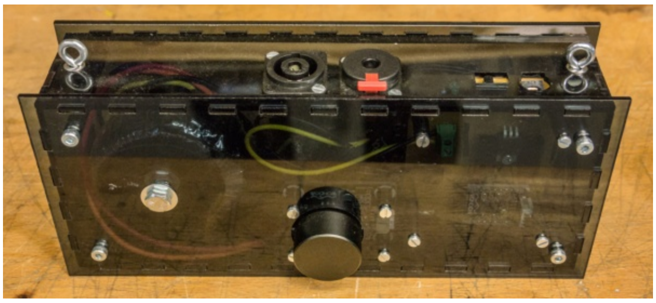

Figure 4: Custom Amplifier. Shown on this photograph is a custom designed amplifier that is used to drive the piezoelectric films as loudspeakers. Visible on the top side of the amplifier are (from left to right): a Speakon socket for connecting the loudspeaker region, a Jack socket for connecting the audio interface, a switch for turning the amplifier on and off, and a barrel socket for connecting a power supply. Visible on the front of the amplifier is the volume control knob. Barely visible through the acrylic surface are (from left to

[6] Sure Electronics 60 Watt 3 Ohm Class D Audio Amplifier Board - TPA3118
[7] Sure Electronics Control Module VC01-M62429
[8] Triad VPT12-2080

right): a transformer coil, a volume control electronics board, and a power regulation board. The regular amplifier board is not visible since it is mounted behind the transformer coil.

3.2 Software

The software part serves the purpose of controlling the overall volume and frequency content of the acoustic feedback signal. In addition, the software also allows to differently route a microphone region to a loudspeaker region.

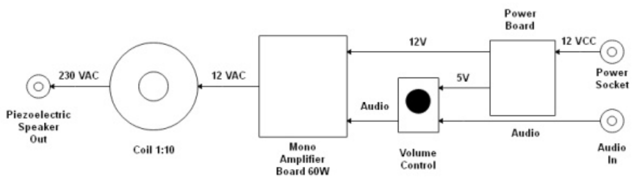

Figure 5: Schematic depiction of the custom amplifier electronics. Visible from right to left are: two sockets for electrical power (top) and audio signal (bottom), a power regulation board, a 60 Watt Mono amplifier board, a step-up transformer coil, and a socket that outputs the fully amplified audio signal to the loudspeaker region of a piezoelectric film.

The software has been custom designed in the Max/MSP programming environment. A schematic depiction of the digital signal processing stages that have been implemented is shown in figure 6. These stages include: an analogue to digital conversion of the microphone signal, a gain unit for amplifying the converted microphone signal, a high-pass filter to remove DC-offset, a low-pass filter to remove high frequency content, a limiter to stabilize the audio volume, a routing matrix for connecting the pre-processed microphone signal to a loudspeaker region, a gain unit for attenuating the loudspeaker signal, and a digital to analogue conversion for outputting the final audio signal to the amplifier electronics. Apart from the routing matrix, all the other signal processing stages exist twice and run in two parallel pipelines, one pipeline for each microphone to loudspeaker feedback connection.

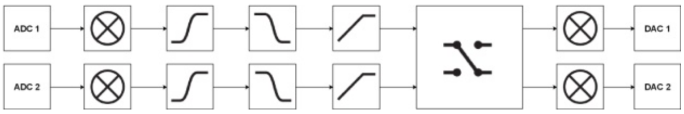

Figure 6: Schematic depiction of the feedback audio signal processing pipelines. Depicted are from left to right: an analogue to digital signal converter, a gain unit, a high pass filter, a low pass filter, a limiter, and signal routing matrix, a second gain unit, and a digital to analogue converter.

Some of the control parameters of the signal processing pipelines have been exposed for interaction through a graphical user interface (see figure 7). Apart from choosing among a pre-made set of parameter combinations, the GUI allows users to change the routing among microphone and loudspeaker regions, alter the gain of the microphone and loudspeaker signals, change the cut-off frequencies for the low-pass and high-pass filters, and modify the amplitude threshold of the limiter. This GUI is displayed on and manipulated through a touch screen.

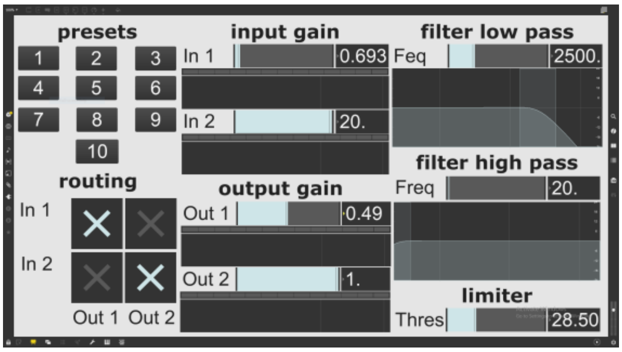

Figure 7: Graphical user interface for the signal processing software. The GUI displays a subset of the control parameters of the digital signal processing

pipeline that links the microphone input to the loudspeaker output for each region on the two piezoelectric films.

4. Acoustic Measurements

Several measurements of the acoustic properties of the two previously described piezoelectric film sheets have been conducted. The first set of measurements quantifies the capability of the piezoelectric material to operate as a loudspeaker. The second and third set of measurements assess the combined functioning of the piezoelectric material as loudspeaker and microphone. For the second set of measurements, the loudspeaker and speaker regions are located on the same film sheet. For the third set of measurements, these regions are located on two different film sheets. All measurements were repeated several times during which the curvature of the film sheets was set to one of the following four shapes: free hanging film (curvature 1), film curved at the bottom (curvature 2), film curved so that its bottom part reaches up to the vertical middle of the film (curvature 3), film curved so that its bottom and top parts are on the same height (curvature 4). The measurements were conducted in a recording booth that is sound proof and exhibits low reverberation (see figure 8). The results of these measurements are provided in the form of sound-pressure level (SPL) plots. These plots have been created with the aid of the free room-acoustics software REW[9].

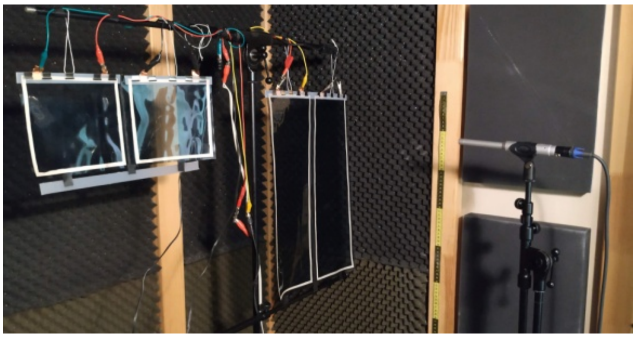

Figure 8: Acoustic measurement setup. Shown on this photograph are two piezoelectric film sheets and a reference microphone.

4.1 Loudspeaker Characteristics

This section describes the results of measuring the loudspeaker characteristics of two differently sized piezoelectric film sheets. For the purpose of the measurement, the frequency of sine wave audio signal was linearly interpolated over the range from 20 Hz to 22050 Hz and sent to the loudspeakers. The emitted loudspeaker signal was recorded using a calibrated reference microphone[10]. The resulting SPL plots are shown in figure 9.

The SPL plot for the small piezoelectric film sheet permits the following observations. The maximum sound pressure level lies in between 1.5 kHz and 13.5 kHz. The amplitude in this frequency range increases when the film changes shape from curvature 1 to curvature 2. When the film is further bent to curvature 3 and curvature 4, the frequency range splits into a lower frequency region (1.5 kHz to 4.5k Hz) whose amplitude decreases and an upper frequency region (4.5 kHz to 13.5 kHz) whose amplitude further increases. In more detail, the following spectral changes of the loudspeaker signal can be observed as a result of increasingly bending the small film sheet. Two peaks present at 3.8 kHz and 5.5 kHz under curvature 1 increase in

[9] https://www.roomeqwizard.com/

[10] Dayton Audio EMM-6

amplitude and then merge into a single peak at 4.1 kHz under curvature 2. This single peaks shifts to 4.35 kHz under curvature 3, and 5.2 kHz under curvature 4. One peak at 7.2 kHz under curvature 1 increases and shifts to 7.8 kHz under curvature 2, then disappears under curvature 3, and reappears at 9 kHz under curvature 4.

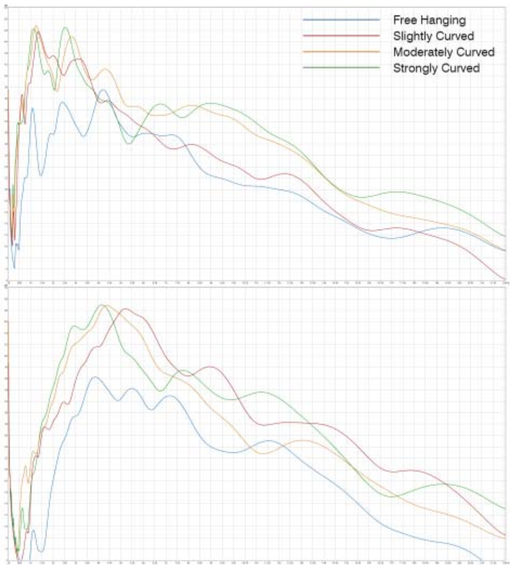

Figure 9: Loudspeaker measurements. Shown here are the SPL curves for the large (top) and small (bottom) piezoelectric film sheets.

The SPL plot for the large piezoelectric film sheet permits the following observations. The amplitude emitted by this loudspeaker is not louder than that of the small piezoelectric film sheet but its frequency range extends further towards lower frequencies. The maximum sound pressure level for the large film lies in between 0.4 kHz and 13.5 kHz. The amplitude increases over this frequency range when the film changes shape from curvature 1 to curvature 2. As the film is further bent to curvature 3 and 4, the amplitude of the lower frequency range (from 0.4 kHz to 5.9 kHz) remains unchanged. On the other hand, the amplitude in the upper frequency range (from 5.0 kHz to 13 kHz) decreases when the bending of the film increases from curvature 3 to curvature 4. This effect is different from the observations for the small film sheet. In more detail the following spectral changes in the loudspeaker signal can be observed as a result of increasingly bending the large film sheet. One peak present at 1.1 kHz under curvature 1 stays at the same frequency but widens under curvature 2, then shifts to 1.25 kHz under curvature 3, and further widens and shifts to 1.35 kHz under curvature 4. Another peak at 2.4 kHz under curvature 1 slightly shifts to 2.5 kHz under curvature 2, then shifts to 2.8 kHz under curvature 3, and widens, diminishes, and shifts to 3.2 kHz under curvature 4. A third peak located at 4.2 kHz under curvature 1 diminishes and shifts to 4.4 kHz under curvature 2, and disappears under curvature 3 and 4.

4.2 Internal Loudspeaker-Microphone Coupling

In this section, measurements are presented of the acoustic coupling between a loudspeaker and microphone region that are both located on the same piezoelectric film sheet. Accordingly, these measurements quantify the capability of the microphone region to pick up acoustic signals that propagate mechanically through the surface of the film material. For the purpose of the measurements, the same sine wave signal frequency sweep as in the previous measurements was used. The resulting SPL plots are shown in figure 10.

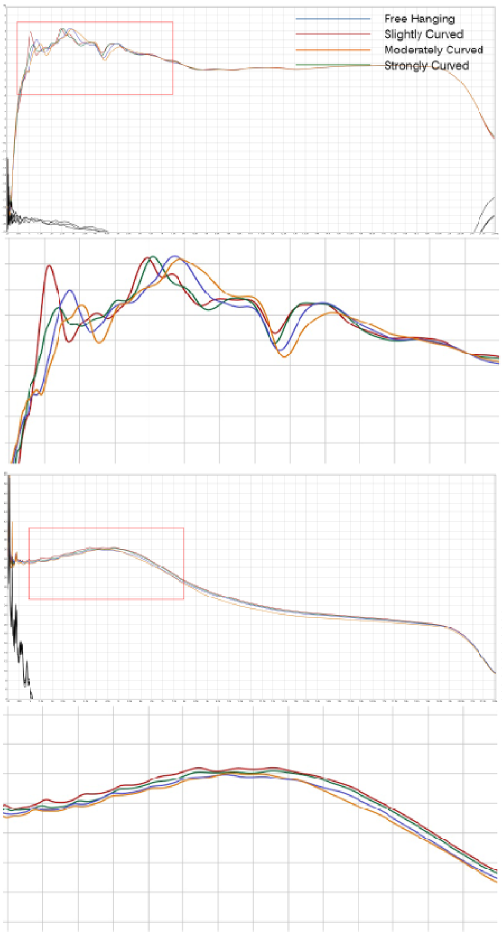

Figure 10: Internal loudspeaker and microphone measurements. Shown here are the SPL curves for the large (top half) and small (bottom half) piezoelectric film sheets across the full measurement spectrum and in a subregion of the spectrum within which the amplitude is highest.

The SPL plot for the small piezoelectric film sheet permits the following observations. The maximum sound pressure level lies in between 0.8 kHz and 8.0 kHz. Compared to the previous measurements with an external reference microphone, this SPL distribution indicates that the piezoelectric region is significantly inferior at picking up high frequencies. But what is more striking is the difference in shape of the SPL curve when compared to the previous measurements. Here, the SPL curve is much smoother and flatter. This indicates that a placement of the loudspeaker and microphone regions on the same film sheet leads to a compensation and cancellation of each other's acoustic particularities.

The SPL plot for the large piezoelectric film sheet permits the following observations. Overall, the sensitivity of the large microphone region is drastically lower as compared to the small microphone region. The maximum sound pressure level lies in between 1.0 kHz and 6.5 kHz. This frequency range is again much smaller when compared to the measurements with an external reference microphone. Contrary to the measurements of the small film sheet, the spectrum is not flat but exhibits distinct peaks. One peak is present 1.1 kHz under curvature one, this peak decreases and shifts slightly to 1.2 kHz under curvature 2, then increases and shifts to 1.35 kHz under curvature 3, and finally decreases and shifts to 1.5 kHz under curvature 4. Another peak at 2.45 kHz under curvature 1 minimally shifts to 2.5 kHz under curvature 2, then shifts to 2.85 kHz under curvature 3, and finally reaches 3 kHz under curvature 4. A third peak exists at 4.8 kHz under curvature 1 and 2, this peak shifts to 5.0 kHz under curvature 3, and decreases and shifts to 5.2 kHz under curvature 4. From these observation it can be concluded that the acoustic particularities of the large microphone and loudspeaker regions don't cancel each other out as was the case with the small film sheet. Rather, these peculiarities persist and change in a concerted manner as the bending of the film sheet affects both the loudspeaker and microphone regions in a similar manner.

4.3 External Loudspeaker-Microphone Coupling

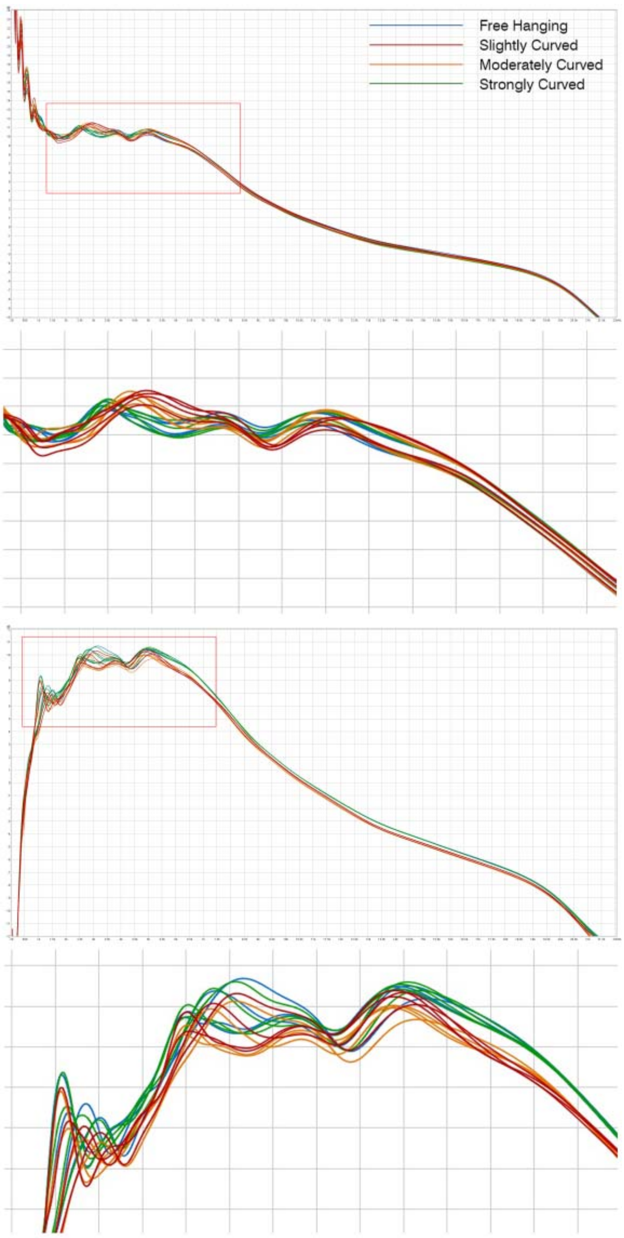

Figure 11: External loudspeaker and microphone measurements. The SPL curve on the left corresponds to a setting in which the sweep signal is sent to the loudspeaker region on the small film sheet and the microphone region on the large film is used for measuring. The SPL curve on the right corresponds to the opposite setting. The SPL plots at the top depict the entire frequency range of the measurments. The SPL plots at the bottom show a subregion of the spectrum within which the amplitude is highest.

In this section, measurements are presented of the acoustic coupling between a loudspeaker and microphone region that are each located on a different piezoelectric film sheet. As in the previous tests, these measurements quantify the capability of the microphone region to pick up acoustic signals that propagate mechanically through the surface of the film material. But contrary to the previous tests, the microphone and loudspeaker regions now possess a different size and they can be curved independently from each other. For the purpose of the measurements, the same sine wave signal frequency sweep as in the previous measurements was used. This signal is sent to the loudspeaker region on a first film sheet, the output from the microphone region on this first film is then routed through Max/MSP to the loudspeaker region on the second film, and the output from the microphone region on this second film is finally measured. The resulting SPL plots are shown in figure 11.

For the first set of measurements, the sine signal is output through the loudspeaker region on the small film sheet and the microphone region on the large film sheet is used for measuring. This setting combines the weak microphone characteristics of the large film with the narrow frequency range of the small film. The resulting SPL plot permits the following observations. The maximum sound pressure level lies in between 0.8 kHz and 8.5 kHz. Changes in the curvature of the small film have no effects on amplitude levels and cause no shifts in the frequency spectrum. Changes in the curvature of the large film give rise to similar acoustic effects as in the previous measurements.

For the second set of measurements, the sine signal is output through the loudspeaker region on the large film sheet and the microphone region of the small film sheet is used for measuring. This setting combines the stronger microphone characteristics of the small film with the larger frequency range of the large film. The resulting SPL plot permits the following observations. The maximum sound pressure level lies in between 0.02 kHz and 8.0 kHz. Similar to the previous measurements, changes in the curvature of the small film have no effect. Changes in the curvature of the large film have similar effects as in the previous measurements with the notable exception of a disturbance signal that masks features in the SPL plot below 2 kHz. The source of the disturbance signal has not yet been identified.

5. Acoustic Feedback Experiments

Based on the insigths gained from the acoustic measurements, a set of experiments was conducted in which the two differently sized piezoelectric film sheets were integrated into an acoustic feedback loop. Throughout these experiments, the sound signal that was measured and emitted by the microphone and loudspeaker regions was no longer externally produced but arose through positive feedback from minimal internal fluctuations within the acoustic setup. These fluctations were reinforced through an acoustic feedback loop which eventually gave prominence to those frequencies for which the pizeoelecric material was particulary sensitive in their detection or efficient in their emission.

The purpose of these experiments was to evaluate the potential of this setup to serve as basis for an interactive and generative sound installation. These evaluations focused on the capability of the two interconnected film sheets to maintain a self-sustained acoustic output whose sonic quality would gradually change over time due to the dynamics of the smart material's internal electrophysical processes and the sensitivity of these processes with respect to changes in the material's shape.

All experiments were conducted in a similar manner. A particular combination of parameters for the digital signal processing pipelines was chosen at the onset of the experiment. After that, the installation was left alone until the audible output stabilized and stopped changing its sonic characteristics. Once this happened, a slight manual change in the curvature of one or both of the film sheets was applied in order to initiate a new transisition phase throughout which the sonic characteristics of the audio signal gradually changed before eventually stablizing again.

Several parameter combinations have been tested. For some of these tests, audio recordings are available online. In the following list, several abbreviations are being used: ML (microphone large region), MS (microphone small region), LL (loudspeaker large region), LS (loudspeaker small region), LP (low pass filter), HP (high pass filter)

1: acoustic feedback between ML and LL. Cutoff Frequencies HP 20 Hz and LP 10 kHz.

2. acoustic feedback between MS and LS. Cutoff Frequencies HP 20 Hz and LP 10 kHz.

3. acoustic feedback between ML and LS and between MS and LL. Cutoff Frequencies HP 20 Hz and LP 10 kHz.

4. acoustic feedback between ML and LL. Cutoff Frequencies HP 20 Hz and LP 2.5 kHz.

5. acoustic feedback between MS and LS. Cutoff Frequencies HP 20 Hz and LP 2.5 kHz.

6. acoustic feedback between ML and LS and between MS and LL. Cutoff Frequencies HP 20 Hz and LP 2.5 kHz[11].

7. acoustic feedback between ML and LL and between MS and LS. Cutoff Frequencies HP 20 Hz and LP 2.5 kHz[12].

8. acoustic feedback between ML and LL, between ML snd LS, between MS and LL, and between MS and LS. Cutoff Frequencies HP 20 Hz and LP 2.5 kHz[13].

9. acoustic feedback between ML and LL, between ML snd LS, between MS and LL, and between MS and LS. Cutoff Frequencies HP 20 Hz and LP 1.5 kHz[14].

10. acoustic feedback between ML and LL, between ML snd LS, between MS and LL, and between MS and LS. Cutoff Frequencies HP 20 Hz and LP 300 Hz[15].

6. Discussion

The method that is followed in this project consists of a combination of an analytical quantification of the acoustic properties of piezoelectric materials and qualitative experiments for evaluating the aeshetic and generative possibilities of these materials. The acoustic measurements have proven to be valuable for gaining an understanding of the diversity of the acoustic characteristics of these materials when being used as either microphones or loudspeakers and how these characteristics are affected by the shape and size of the materials. Even by using only two differently sized film sheets, a clear correlation could be identified between the acoustic properties, size and shape of these materials. The main insights gained are as follows: The size of the region on the piezoelectric film material that is used as loudspeaker affects not only the spectral range of the acoustic output but also the location of frequency peaks. This causes differently sized film sheets to possess a different acoustic characteristics. Bending of a piezoelectric film causes the frequency peaks in the loudspeaker output to almost always shift to higher frequencies. While shifting, the peaks occasionally change in width and amplitude. This change is dependent on the size of the film sheet and the amount of bending. The larger the region of a piezoelectric film sheet, the lower its sensitivity as a microphone. If both the microphone and loudspeaker reagions are located on the same film sheet and this sheet has a small size, then the peaks in the spectrum of the loudspeaker's output disappear when measured by a microphone region. This effect is not observed for larger film sheets.

These observations can be used as guiding principles for designing the sonic and interactive properties of a sound installation. This includes for instance the choice of size for film sheets in order to control the emission spectrum of a loudspeaker and/or the sensitivity of a microphone. And this also includes the choice of size when combining microphone and loudspeaker regions on the same film since this affects the strength of the acoustic effects of bending a film sheet and this in turn controls the level of interactivity that is provided through a direct manipulation of a film sheet's shape.

On the other hand, it is much more difficult to anticipate how the piezoelectric film sheets respond to and affect acoustic feedback. For this publication, the evaluation of the correlation between material properties and acoustic feedback

[11] audio recording 1
[12] audio recording 2
[13] audio recording 3
[14] audio recording 4
[15] audio recording 5

has been conducted in a qualitative and explorative manner only. To follow a similar systematic and quantative approach as was used for the characterisation of the acoustic properties of the piezoeelectric materials would require much more effort. For such an approach, the amplification effects of positive feedback pose a particular challenge, in that slightest deviations in the measurement situation can lead to different results. Sources of such deviations are both internal to the setup of the film sheets (e.g. stiffness of the attachment of the film to a support structure or eveness of the curvature) or external to the setup (e.g. ambient temperature and humidity). This sensitivity to the conditions of measurement renders an exhaustive assessment of the factors that affect the sonic result of acoustic feedback very difficult. While such a level of unpredictability can be considered advantagous for realizing a generative installation, it also hampers the possibility to scale the setup in a somewhat planned manner beyond a setting that includes only two piezoelectric film sheets.

7. Conclusion

Smart materials possess a great potential in the context of generative art. This project represents the author's first attempt at integrating such materials into a generative installation. The procedure that has been chosen is practical and tries to address as many steps as possible that are necessary for covering an entire creation process from the selection of materials to a final artwork. At the core of this procedure lies a combination that consists of a systematic and quantitive assessement of the properties of the chosen smart material and an explorative and qualitative evaluation of the application of this material for realizing a generative artwork. The author is convinced that such a combination is crucial for gaining the skills to work with smart materials in a generative art context. This publication is the result of putting this claim to a practical test.

While the outcome of this test confirms the usefullness of the chosen approach, there remain several ceveats. These caveats have to do with the fact that the author has taken a few shortcuts in order to conduct the study in a manageable amount of time. By working with piezoelectric films, a material has been chosen that is unlike many other smart materials readily available through commercial channels and that is already known to be suitable for use as a loudspeaker. This has alleviated the need for studying in detail the physicochemical properties of the smart material, a type of research that would hardly be possible to conduct without expertise in material science. Also, the final installation must be considered a somewhat minimalistic demonstration of what a smart-materials based generative sound installation could potentially look like. It can be assumed that some of the main challenges for integrating smart materials into a generative artwork are yet to be encountered when trying to reach a more sophisticated outcome.

Nevertheless, the author assumes that the insights gained from this project can be transferred for working with other smart materials even when aiming for a more ambitious artistic outcome. It is therefore hoped, that this publication contributes to a diversification of generative art practice to include also non-computer based current and future technologies.

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