Audio feedback on metal panels and emotion detection for sound classification in low-hierarchy performance spaces

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Abstract. Social inequality in both the classical music production and consumption practices is undoubtedly at the base of the lack of involvement of the so-called new audiences in the contemporary music scene and it has been observed that timbre-based approaches to synthesis tends to favour listening and interaction when people have no music background. The present paper investigates the use of audio and electromagnetic feedback for the stimulation of vibration in metal panels and metallic musical instruments within the frame of interactive sound installations and compositions to pursue the exploration of less hierarchical structures within the performance space. A variety of feedback algorithms implemented for those works will be described along with the machine learning techniques used to expand the human-machine relationship via web-applications, which allow for remote interaction of the audience. Classification of sound according to its emotional content was used because non-musicians tend to relate to music mainly through their emotional response to it. Sound analysis and re-synthesis enabled the production of control data to steer AC devices as well as regulate the activation of the audio feedback algorithms. Given its non-linearity and its reluctance to control, feedback turned out to be particularly successful in the generation of a vast variety of timbre-based audio material and agency, thus laying the ground for free improvisation and interaction within the performance space.

Keywords: audio feedback, electromagnetic feedback, Convolutional Neural Networks, emotion detection, audience participation, intermedia, hierarchy, agency.

Introduction

The present paper mainly investigates the use of audio feedback for the stimulation of vibration in metal panels and metallic musical instruments within the frame of sound installations and compositions. Some of the specific feedback algorithms used in these works will be described as well as how common metallic objects can be regarded as hybrid electroacoustic instruments for the benefits of non-musicians, who develop short improvisations with them without feeling intimidated as it is the case when they happen to interact with musical instruments with a long history, specific repertoire and playing techniques.

Undoubtedly, the fascination for audio feedback is partially due to its unpredictability, its tendency to resist repetition and its intrinsic bidirectional ability to foster interactivity. Those features alone provide valid agency for free improvisation. That embodies what Di Scipio calls 'agentive potential of complex feedback systems'[1] and

[1] Di Scipio, 2022.

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what Nakamura's words refers to when he states that 'it seems like there is quite an equal relationship between this machine and me'[2]. Especially when employed to activate vibration in metallic objects, audio feedback tends to resist the dominance of the performer/composer and, hence, displays a natural reluctance to hierarchy. This resistance fits particularly well with an interactive sonic environment which aims to reduce hierarchy in the performance space[3]. According to Nakamura 'you can't be a feedback improviser when you have your brains filled with your big beautiful pictures prior to your performance'[4]. Although not necessarily aimed at non-musicians, Nakamura's statement points out how easy it becomes to find a way to interact with a hybrid instrument which embed such a system if one has no specific sonic plans for it, as it is mainly the case for non-musicians. Moreover, Landy's work (2011) seems to have proven that, when non-musicians experience sound, complex frequency content, thus rich timbral situations, favours listening, and the sparse distribution of sources in the performance space can offer multiple listening perspectives to the audience as an alternative to a sweet spot structural strategy[5]. The idea of populating the space with objects which emit different sounds along with the use of audio feedback clearly relates to some of David Tudor's works. In the *Rainforest* series[6] and *Microphone*[7], the material mediator is absolutely necessary for the production of sound. The agency of the audience shifts remotely in *AmotIon*, an installation with which people can interact through the use of a web-application. In this case, the feedback loops are framed within a larger human-machine loop which integrates machine learning algorithms for determining choices with regard to sound synthesis, instrumentation and agency.

In the following sections of the paper I will be describing how *Intermezzo 4* is an installation which creates a frame for musicians and non-musicians to realize free improvisations through the use of audio feedback on metal panels and small DC motors to change the position of some of the driving elements. Another section will focus on how a system for audio feedback on metal panels was embedded within a larger human-machine loop through a web-application for Emotion Detection implemented via Convolutional Neural Networks (CNNs). The section which precedes the conclusions concentrates on audio feedback systems directly applied to musical instruments and on my plans for future research. A classification of the feedback systems described according to the schema suggested by Sanfilippo e Valle (2013) will be attempted and discussed in the conclusions.

[2] Nakamura, 2002: 5.

[3] Rosani, 2020.

[4] Nakamura, 2002: 5.

[5] Rosani, 2017.

[6] Rogalsky, 2002.

[7] Space Echo, n.d.

Audio feedback and DC motors: Intermezzo 4

While I was studying for my Phd at Goldsmiths, University of London, I had the chance to take part in the New Music/ Québec – UK Exchange and spent a month in Montreal working with Ensemble In Extensio. In that occasion, I met Canadian percussionist Tom Jacques, who asked me to collaborate to a Canada Art Council supported project on a augmented vibraphone. During a Subnet residency at the Human-Computer Interaction Center of the University of Salzburg (SubnetAIR n.d.) we started experimenting on how to stimulate the vibration of the vibraphone tone bars via feedback. The idea of using feedback to augment the vibraphone came to me while reading about the EMvibe project being developed at the Augmented Instruments Laboratory at Queen Mary University of London[8]. The EMvibe system required a complex tuning procedure to stimulate the correct harmonics of the vibration tone bars, while I thought that a feedback-based system similar to how previous augmented instruments had been developed in the same lab might spare the need for that procedure. Since the residency at HCI turned out to be too brief to allow for the development of a feedback system that could also be easily transportable back to Canada, I continued the exploration of audio feedback within another project of mine. In particular, I implemented audio feedback on metal panels as thin as 0.5mm which displayed a way stronger proclivity than the thick tone bars of the vibraphone to react to feedback. The project ended up becoming *Intermezzo 4* (2019), an installation for audio feedback and DC motors on metal panels. The installation consists of 5 metal panels, on which one or two contact microphones are hung. On each of the 4 panels hung on metal stands there can be either Dayton sonic exciters or speaker drivers. While the former are fixed in their position, the latter can be moved by hand or via the use of DC motors controlled with a MIDI controller. The fifth metal panel, which does not hang but can be moved around the performance space is made to vibrate via a feedback loop between a contact microphone and a lifting magnet, which creates a different timbre in comparison to the other drivers and is smaller. That makes actions like twisting and torquing of the panel easier, since the lifting magnet is quite small and, hence, does not interfere with the handling of the panel or risk dropping from it. The frequency content of the feedback loops change as the speaker drivers move along the surface of a metal panel either manually or via the DC motor connected to it (see Fig. 1). It is also possible to easily move the position of the contact microphones – clip Korg CM-300 contact microphones -- on the edges of the metal panels. As one removes the microphone from the panel, the sound stops. Therefore, that is an action I often pursue during performances, since it makes it clear to the audience that I am not necessarily projecting sound through the sonic exciters or speaker drivers.

Since the position of the sonic exciters is fixed, the sonic loops which make use of these drivers varies algorithmically. The strategies implemented for the exciters aim to generate interferences by activating two exciters on the same panel, feeding the input

[8] Britt et al., 2012.

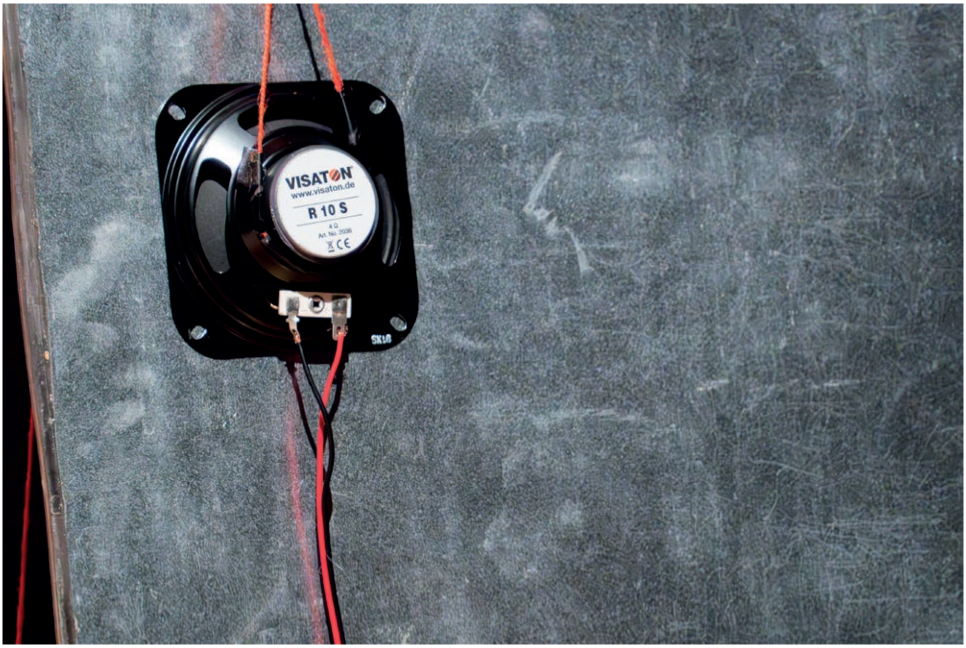

Figure 1. Speaker driver sliding along the surface of the metal panel. Photo credit: Laura Stefanie Kleindopp.

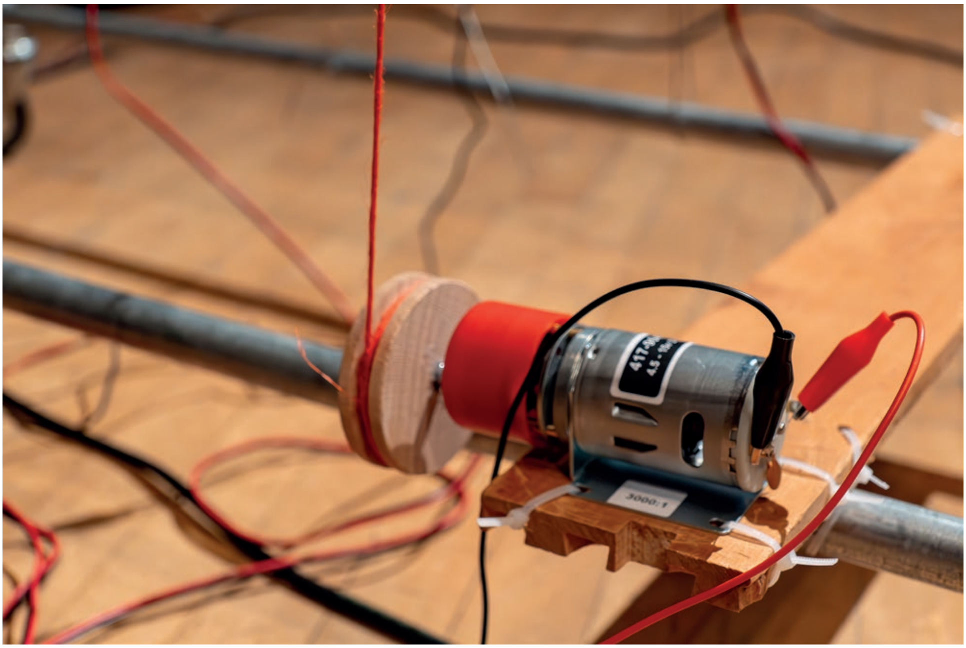

Figure 2. DC motor supporting movement of the speaker driver. Laura Stefanie Kleindopp.

from two different microphones to the same exciter, or a combination of the two techniques. Alternatively, the feedback loops are varied digitally as it is described below. In all figures, I indicated the contact microphones as CM followed by 1 or 2, since on each metal panel there were between one and two microphones. Similarly, I used SE to indicate a sonic exciter followed by the correspondent number.

Fig. 3 – Algorithm 1

The simplest algorithm (Larsen) includes a limiter with a threshold that is regulated via the MIDI controller or automation. The signal from each of the two contact microphones is routed to the correspondent sonic exciter with the exception of the first, which can also optionally leak into the second output. This option is valid also with any of the other algorithms and, hence, the first contact microphone has been added with dash lines in all of the following schemes too.

Fig. 4 – Algorithm 2

A second algorithm implements a variable delay line with a feedback line – comb FIR filter. The length of the delay line and feedback factor can be adjusted via a MIDI controller or automation.

Fig. 4 – Algorithm 3

Within the third algorithm a concatenation of all-pass filters as in the [rev1~] object created by Miller Puckette (2007) is embedded within the second algorithm. The

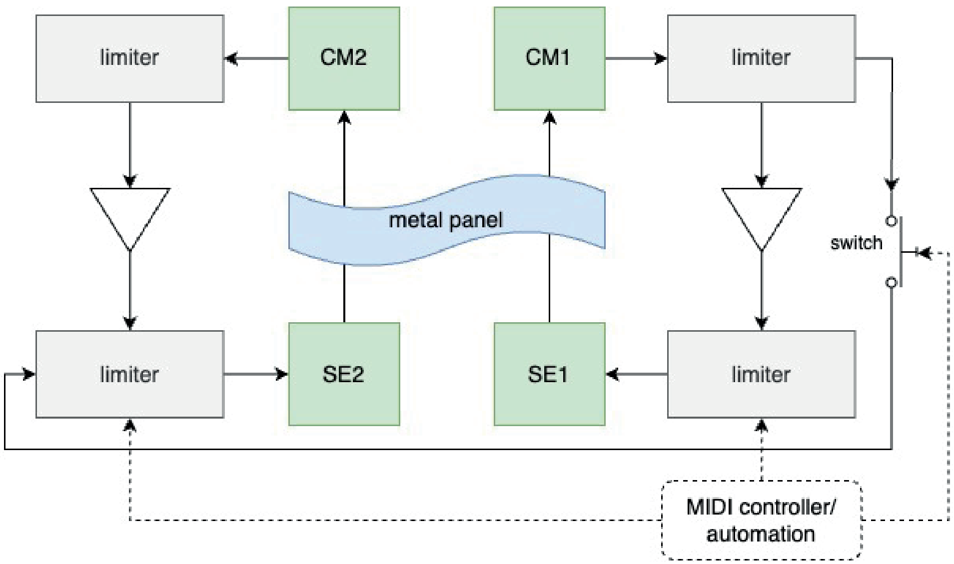

Figure 3. Algorithm 1: Larsen and second contact microphone (optional).

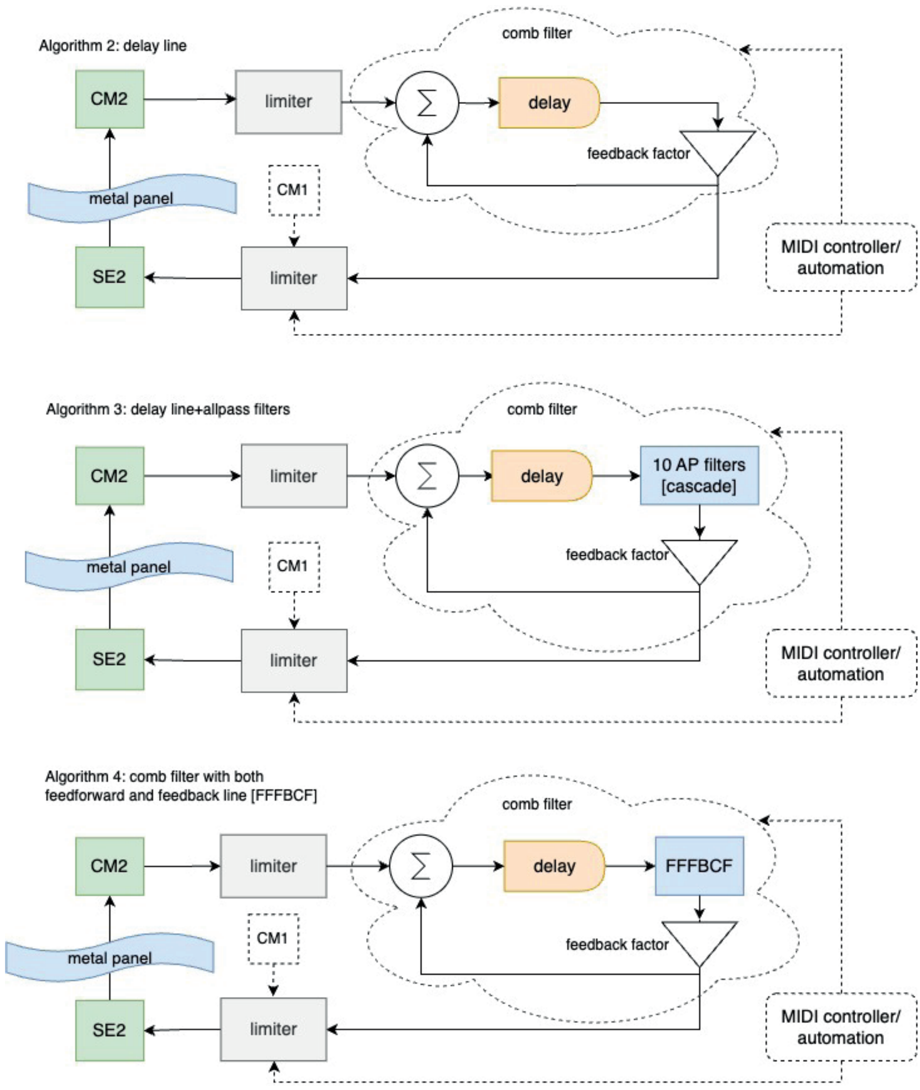

Figure 4. Algorithms 2-4: delay line, delay line+allpass filters, delay line with feedforward and feedback line.

reverb time can be controlled via MIDI controller while before every activation the filters are cleared.

Fig. 4 – Algorithm 4

The fourth algorithm implements a comb filter with feedback as well as feedforward line embedded within the second algorithm. Both frequency and decay time can be controlled via MIDI.

The last 3 algorithms all include modulations.

Fig. 5 – Algorithm 5

The fifth algorithm implements ring modulation between the feedback sound and an sinusoidal LFO. The MIDI controller enable control over the frequency of the oscillator.

Fig. 5 – Algorithm 6

Here a delay line similar to the one in the second algorithm is followed by a ring modulator. All parameters can be controlled and, hence, varied.

Fig. 5 – Algorithm 7

The last algorithm implements phase modulation between what would otherwise be a simple feedback signal (Larsen) and an oscillator. The resulting signal is then fed to a ring modulator. The MIDI controller enables variations of the modulation index, the frequency of the carrier and the oscillation frequency of the LFO in the ring modulator.

The first 4 algorithms can be freely selected for panel 2 via the MIDI controller, while the last 3 algorithm can be selected on panel 3. Panel 1 is set up with 2 speaker drivers which can both be moved via DC motors up and down the surface of the metal panels and, hence, already varies the frequency content of the feedback loops through the different positioning of the transducers involved. Panel 4 is equipped with a speaker driver which can be moved by hand and panel 5 is also usually handled by hand, as the lifting magnet mentioned above is attached to it. Sound examples of the outputs produced by the algorithms and by different routings of the microphone inputs to the driver outputs are provided in the reference section (Rosani, 2025).

Intermezzo 4 has 3 different settings. The first one turns the installation in a fully automated installation and is activated when no human interaction is required, although that is still possible. Audience members interacting with the installation at the Huddersfield Contemporary Music Festival (hcmf) are depicted in Fig. 6.

The second setting entails partial automation and that is the setting I use when I develop an improvisation with no other collaborators. The third setting is totally manual and that is the one I activate when I work with either musicians or non-musicians. The first 2 settings were mainly used in the first years of the installation[9], while the last setting was used more recently when I improvised with the students of the Leeds College of Music (Rosani, 2025) and in Salzburg with Ensemble NAMES (Sounding Sculptures, 2021). Nevertheless, not all the algorithms had been implemented by 2021. They are now fully functional and will be used for the performance at Festival Mixtur in October 2024. There I will be improvising with the installation myself, at

[9] Huddersfield Contemporary Music Festival, 2019; Susch Muzeum, 2021.

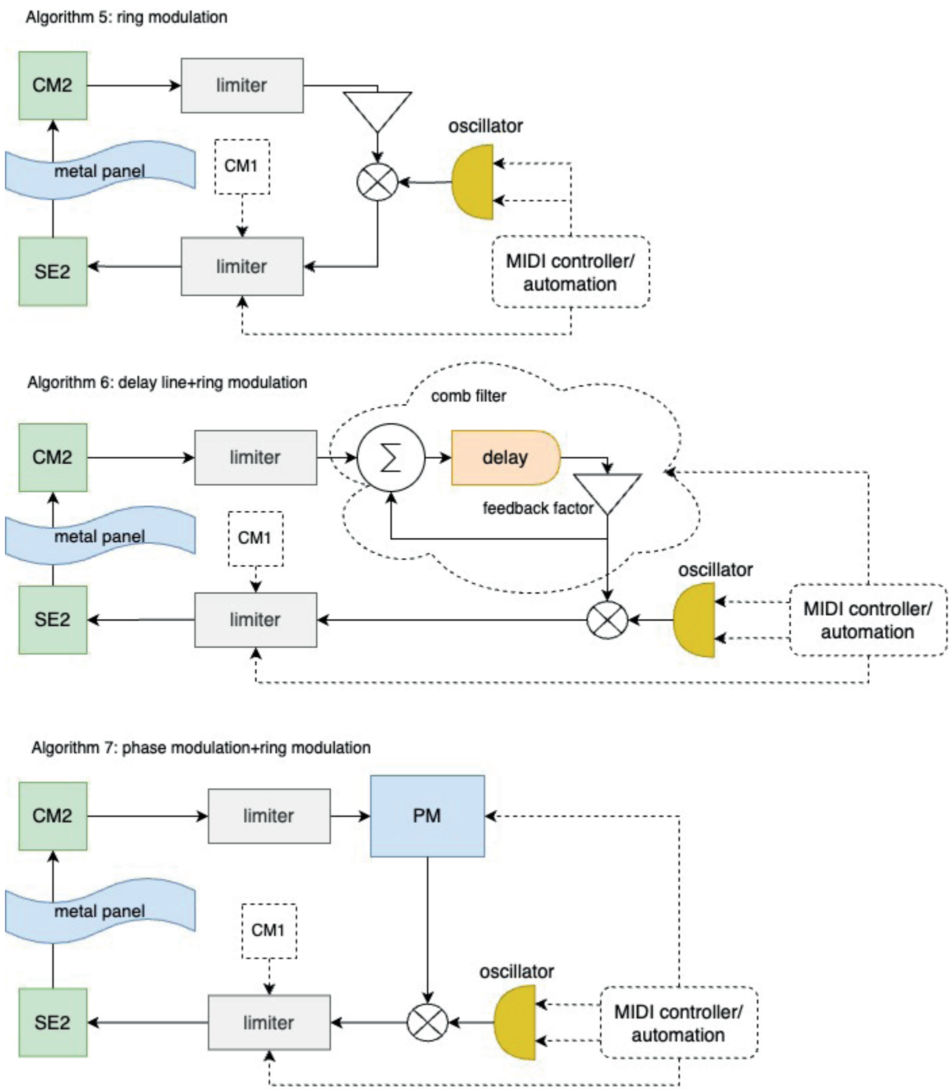

Figure 5. Algorithms 5-7: ring modulation, delay line+ring modulation, phase modulation+ring modulation.

times leave the first setting active and finally develop improvisations with the audience members and the students from ESMUC. A link to the video of the performance with Ensemble NAMES is available in the reference section (NAMES, 2021). While I was in residence at Muzeum Susch, visual artist Agnieszka Mastalerz (Susch, 2021) shot brief videos of audience members interacting with *Intermezzo 4* (Susch, 2021). A few seconds of the improvisation developed by the students of the Leeds Music College with my installation were recorded and are available in the reference section (Sounds Like THIS, 2020).

Figure 6. Audience members interact with *Intermezzo 4* at hcmf 2019. Photo credit: Brian Slater.

Audio feedback and Emotion Detection

In 2021, a combination of residencies gave me the opportunity to move the necessary steps towards the creation of *AmotIon*, an interactive installation for emotion detection implemented via a web-application and audio feedback on metallic objects. During a EASTN-DC residency at ZKM in Karlsruhe I had the chance to start working on emotion classification in voices which then was embedded in an installation for the Internet of Things. These expertise came in handy when I was awarded a residency and project budget of the European platform EMAP/EMARE (AmotIon (2021), n.d.), for which I collaborated with the multimedia center RIXC in Riga (Latvia). In *AmotIon* a web-application uses Convolutional Neural Networks (CNNs) to classify recordings sent by the audience members, who can also access the app remotely. Once the recordings are classified, the information is sent to a local app, which dialogues with Pure Data and activates the feedback loops on metallic objects in the installation space. The reaction of the installation is then recorded and classified into 8 emotional categories. If the result of the classification does not match the emotional content of the recording collected through the global app, the system triggers a second activation of the installation, which again gets recorded and classified. The process

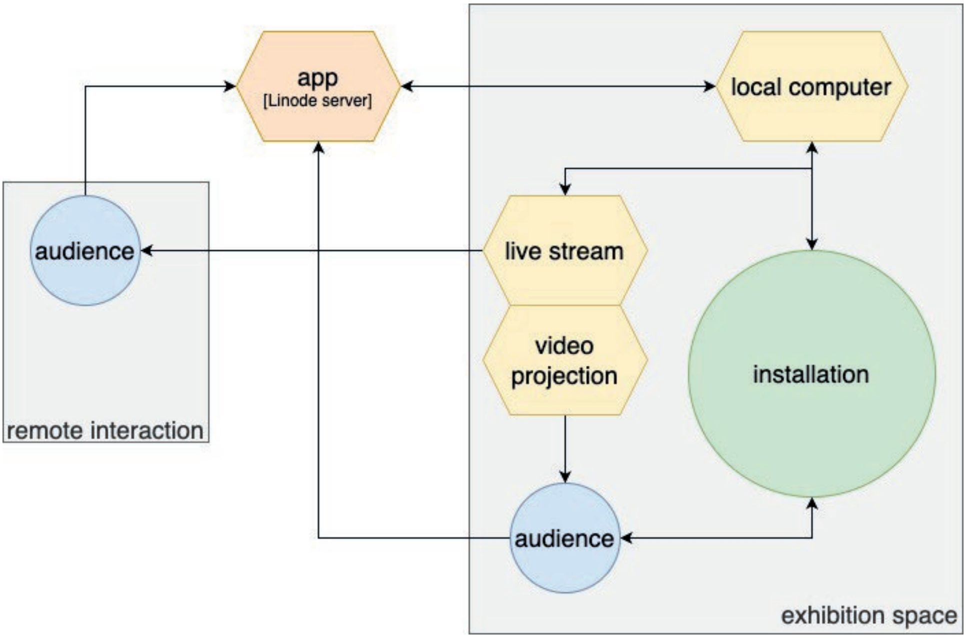

Figure 7. Scheme of the overall architecture and functioning of the installation as a loop.

stops if an emotional match is detected or after 4 repetitions of the comparison have been processed. This loop between the human agent and the machine response aims to implement an emotional attunement between the human sonic intervention and the audio feedback response of the installation. Even remotely the audience members can witness the response of the system via a live streaming from the installation space. The scheme of the whole loop involving audience members – remotely and not, the web-application and the audio feedback on the 3 objects in the installation space is illustrated in Fig. 7.

The web-application was programmed with Python and Flask as an improvisation partner, since once the audience submit their recording the algorithm can randomly choose among 4 actions. After the submitted recording has been classified, an audio file could be re-synthesized once exctracted from a folder where recordings with the same or similar emotion were classified. Alternatively, the audio file could be selected from a folder containing recordings corresponding to emotions contrasting to the one detected in the audience's recording. Otherwise, the algorithm can select an audio file with an emotional content which has no strong correlation to the one in the audience's recording or even not react to it at all. These 4 options somehow cover what a human improviser might choose to do during an improvisation, thus playing something similar, contrasting material, unrelated sounds or remaining quiet. Although the choice of the action is random, a database keeps track of the choices and makes sure that all 4 options are selected with the same frequency.

The re-synthesis of the classified audio files takes place in terms of either dynamic envelope or frequency content. Another random choice the algorithm carries out has to do with which type of feedback algorithm is used and on which of the metallic objects. The feedback loops can activate simple Larsen effect through the opening and closing of the gates between contact microphones and sonic exciters on one or more of the objects according to the dynamic envelope detected in one of the audio files classified by the CNNs model. The envelope can alternatively be stretched in time – 3 different time factors can be selected – to allow for variants in terms of the duration of the reaction the installation displays. A second type of algorithm takes into account the frequency content of the audio file which is being re-sinthesized. Mel-frequency Cepstral Coefficients provide this information in the form of a matrix. When this algorithm is selected, in case no emotional match is detected in the first comparison round, different rows of the matrix are used for the re-synthesis process. Hence, the audio file remains the same, while its frequency content is explored. A third and last type of synthesis algorithm is employed, which uses FM with the frequency information provided by the above mentioned matrix. The resulting sound is not played through sonic exciters but rather diffused via loudspeakers.

Besides 2 large metallic objects – Fig. 8 to 10, *AmotIon* includes a 50 cm diameter tambourine – Fig. 11. A flat contact microphone is attached at the bottom of it along with a sonic exciter. Since the audio feedback loop involves a membrane rather than a metallic surface, the sound resulting from the vibration of this instrument provides one further timbral variant. A brief video of the interaction between the web-application and the audio feedback system is available in the reference section (Nova Synagoga, 2021). Classification of sound according to its emotional content was used because non-musicians tend to relate to music mainly through their emotional response to it and I thought that that could further enhance the process of emotional attunement between human and machine.

A variant of the classification algorithm for emotion detection was used in *Ni anverso ni reverso*, a composition for violin and web-application which was a commission of Vertixe Sonora ensemble and was performed by violinist Roberto Alonso Trillo at the Museo Interactivo da Historia de Lugo during the IX Ciclo de Musica Contemporanea de Lugo (Spain, 2021). In that case the app is used by the violinist as an interface to activate the dynamic envelope re-synthesis through 4 ventilators – Fig. 12. A dpa microphone is used to pick up the instrumental sound and the vocal utterances of the violinist at instants which are either selected by the performer or regulated by the algorithm. The violinist follows the music score according to the result of the classification provided by the emotion detection algorithm. A link to the video of the performance is available in the reference section (Vertixe Sonora, n.d.).

Audio feedback on instruments, electromagnetic feedback and future research

In a couple of cases, I investigated audio feedback applied directly to the body of an instrument. In 2021, I worked with TRIO vis-á-vis and requested of the flutist to attach a lifting magnet on the main body of a bass flute, while a contact microphone

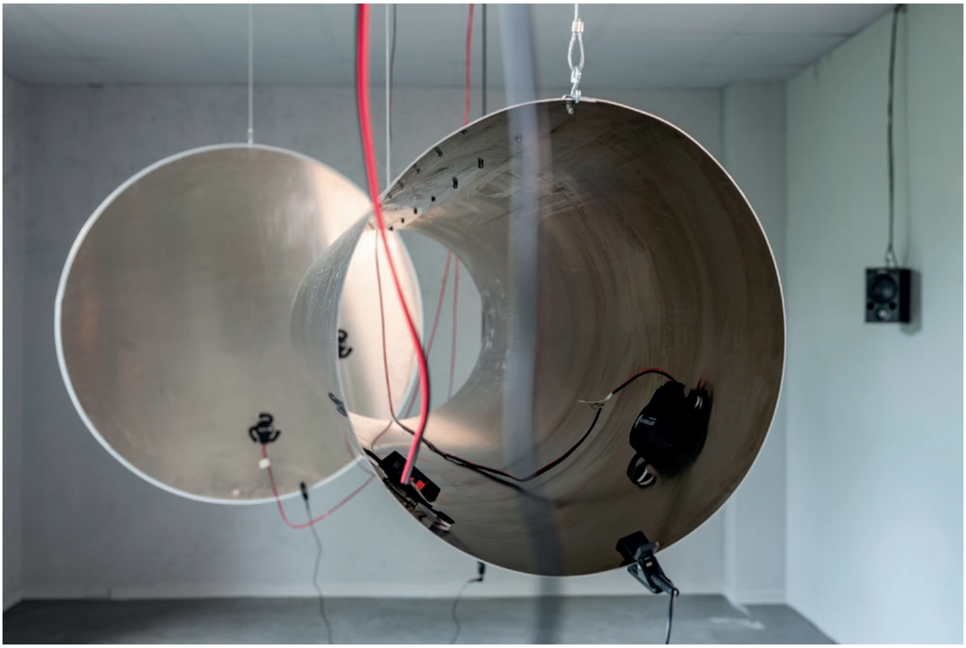

Figure 8. *Amotion* at the Werkleitz Festival (Halle, Germany). Photo credit: Werkleitz Festival 2021 move to … © Werkleitz, Foto Falk Wenzel.

Figure 9. *Amotion* at the Nova Synagoga (Žilina, Slovakia). Dancer interacting with one of the two metal objects during a free improvisation. Photo credit: Luna Mafo.

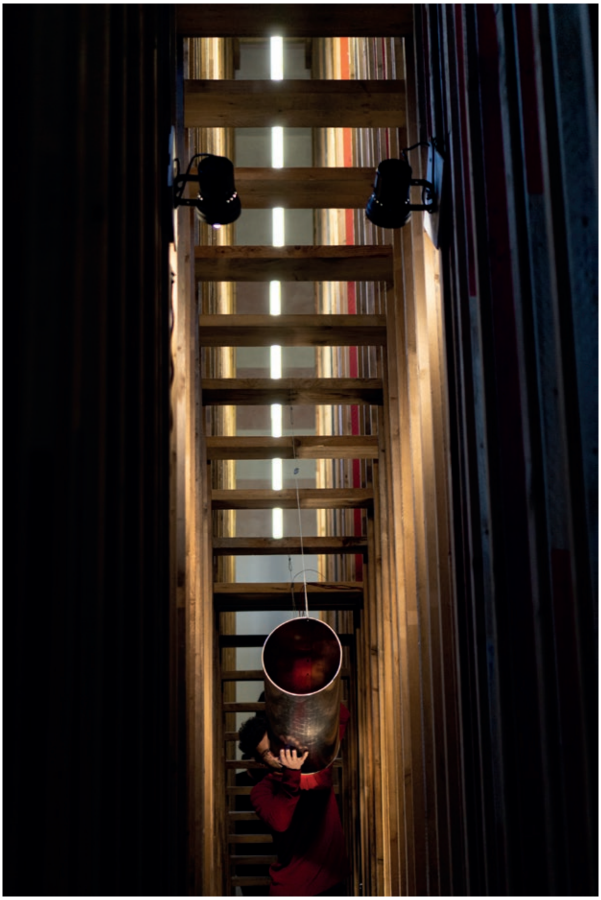

Figure 10. *Amotion* at the Nova Synagoga (Žilina, Slovakia). Visual artist interacting with one of the two metal objects during a free improvisation. Photo credit: Luna Mafo.

was clipped at the exit of the tube[10]. As one could expect, that setting did not provide a variety in the feedback reaction like it might be possible if microphone and driver were arranged respectively at the bore and exit of the tube, as it was the case in some of Collins's works with woodwind and brass instruments or as experienced by Graham with pipes[11], since in my case the feedback environment is the metallic body rather than the air in the tube. Nevertheless, my setting was effective in combination with the energetic percussive sounds in the flute part. The composition integrated also metal panels with an algorithm of filtering for audio feedback. That enabled me to select specific pitches for the audio feedback and to contribute at the re-synthesis of a piece by Claudio Monteverdi along with acoustic instruments.

[10] TRIO vis-á-vis, 2022

[11] Collins, 2002; Di Scipio, 2022.

Figure 11. *Amotion* at the Nova Synagoga (Žilina, Slovakia). Children interacting with the tambourine. Photo credit: Luna Mafo.

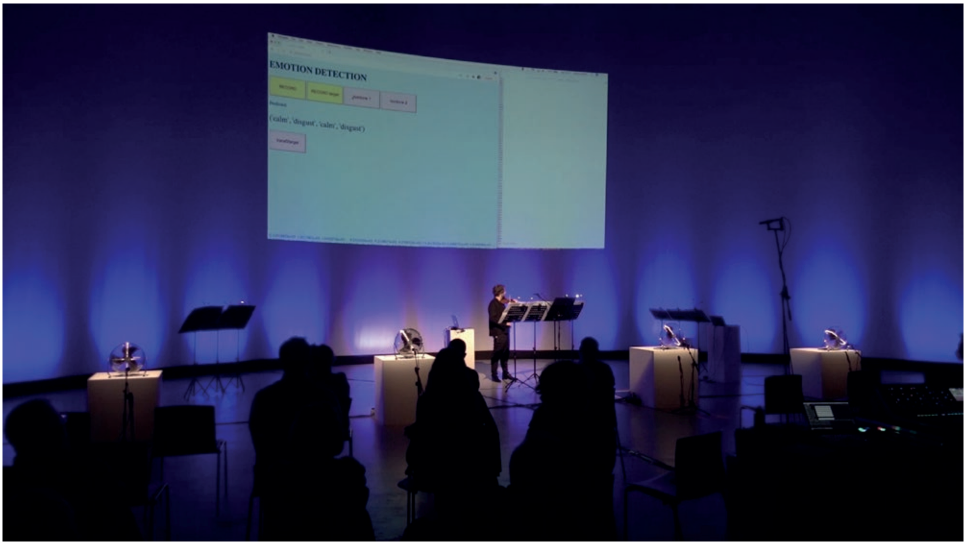

Figure 12. Violinist Roberto Alonso Trillo performs *Ni anverso ni reverso* in Lugo. Photo credit: Vertixe Sonora.

A similar hardware setting was used for *Nomadismo mostruoso*, a composition for natural horn I wrote for Deepa Goonetilleke, with which I could collaborate thanks to a Virtual Partner Residency of the Goethe-Institut (Virtuelle Partner Residenz). The audio feedback subtle variations were employed during the process of changing the crooks. Deepa's movements of the instrument itself during the transitions between the different sections of the piece contributed to vary the frequency content and dynamic envelope of the audio feedback sound.

During a residency at the Experimentalstudio of the Südwestrundfunk (SWR) I investigated the effects of audio feedback between what is commonly referred to as sniffing circuit, thus simply an inductor, and sonic exciters on metal panels. After the residency I carried on the research and could test different types of inductors and combinations of discrete electric components to induce percussive pulses of different occurrence rate in accordance to the results obtained by Nicolas Collins (2020) in his work Mortal coils. My future research plans involve the inclusion of these circuits as interfaces and visual objects with strong symbolic references in a new project with sound-poet Kinga Tóth.

Conclusions

The research outlined above proves that audio feedback can be used successfully to transform metal panels, musical instruments and other objects into hybrid electro-acoustic instruments, with which musicians and non-musicians can develop free improvisations. A large variety of timbral situations originate from manually interacting with such objects, moving the devices involved in the feedback loops via motors and from a series of feedback algorithms implemented in the digital domain. The human-machine relationship can be further expanded with the use of machine learning for the classification of input stimuli and for selecting outputs. Web-applications extend that even to remote audience.

Table 1 shows how the works illustrated in the present paper refer to the parameters highlighted by Sanfilippo e Valle (2013).

Table 1. Parameters in feedback loops with regard to the works illustrated.

	Encoding analog/ digital	Rate audio/ control	Openness closed/open	Trigger internal/ external	Adaptivity adaptive/ non-adaptive	Human-machine interaction absent/present
Intermezzo 4	1	0	1	-1	1	0
AmotIon	1	0	1	-1	-1	1
Ni anverso ni reverso	1	1	1	-1	-1	1
Ai limiti delle soglie II: con moto trasversale	1	0	1	-1	1	1
Nomadismo mostruoso	1	0	1	-1	1	1

In all the works the encoding is digital, since the inputs and outputs are processed by a computer while the systems are definitely always open, since they communicate with a specific material environment, which consists of metal, membrane or AC devices such as ventilators. The flow of data is in all works hybrid, thus audio and control data are fed back, except in the case of *Ni anverso ni reverso*, where the audio input is always first analyzed and control data affect how the loop reacts to the input signal. Once the systems are active, they do not require to be fed since the input signals suffice to trigger the feedback. The works involving CNNs present adaptive properties, since the classification of different and always new audio files entails the feature extraction for the re-synthesis of audio or control outputs. All the works involve a human-machine interaction with the exception of the fully automated setting in *Intermezzo 4*.

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Coding

The coding involved in *AmotIon* and *Ni anverso ni reverso* is publicly available here: https://github.com/xxx-xxx9/Remote-emotions.