Methods for Performing with Feedback in Virtual Acoustics

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ABSTRACT

Live experimental sound practices have explored the use of audio feedback for over sixty years. Such feedback is primarily dependent on the geometries of the space and the position of the sound system in that space. Thus the question arises, within the fixed geometry of a performance space, how might one go about modifying the acoustic characteristic of this space so that different qualities of feedback can be achieved with minimal interventions? Recent advances have seen virtual acoustic systems that enable us to simulate the acoustic characteristics of one space inside another, opening up many aesthetic and artistic possibilities. In this paper we describe a novel method for adapting a virtual acoustic system to create audio feedback effects for live experimental sound and music performances. The virtual acoustic system employed in our work is built from standard room microphones and loudspeakers, running auralizations generated with low latency convolution reverb. Any potential loop gain feedback that would normally occur due to the close proximity of the systems' microphones and loudspeakers is suppressed based on system measurements. By inserting a variable length delay into the system's feedback suppression signal paths – what we call the cancellation signal paths – we temporarily generate a variety of audio feedback frequencies. Further, and most importantly, since the virtual acoustic system is fundamentally a reverberation system, the sound of this feedback is heavily influenced by the acoustics of the virtual space. Several demonstrations of these phenomena are presented in isolation and in the context of a recently composed multimedia work.

1. INTRODUCTION

Audio feedback is the result of a positive loop gain between one or more microphone inputs (or other audio pickups) and the output of one or more speakers. Factors related to the acoustic properties of the performance space or system will determine the feedback frequencies that can result, with the most likely audible feedback frequencies being determined by the lengths of the direct and early reflection paths between the microphones and speakers. In many situations, feedback is undesirable, and techniques are employed to minimize it. Various different techniques for the suppression of feedback in audio systems and performance situations have been proposed and executed for at least the last sixty years [1]. For example, notch filters set at the feedback frequencies can attenuate the likelihood or amplitude of feedback, and adding delay to the microphone signals can lower the feedback frequency. Perhaps one of the most famous examples of feedback suppression – using microphone polarity inversion – can be heard in Alembics iconic work with The Grateful Dead and their crew, which helped to create the famous *The Wall of Sound* system used by the band in the mid-1970's [2]. In virtual acoustic auralization systems, frequency shifting algorithms [3] or other sophisticated filtering processes [4] are similarly used to suppress and minimize feedback. However, while live sound engineers and virtual acoustic system designers want to eliminate feedback, sometimes musical performances incorporate tasteful – and sometimes by intention, not so tasteful – amounts of feedback for aesthetic effect. For example, consider the work of guitarists such as Jimi Hendrix whose signature sound relies heavily on the incorporation of distortion and feedback. That being said, for the purposes of this paper, rather than exploring feedback usage in popular or song-based music traditions, we will focus on the use of feedback phenomena as the primary or significantly important sonic materials in live experimental sound practices, while also demonstrating novel ways to generate and control it.

A full discussion of the use of feedback in live experimental sound practices is beyond the scope of this paper. For those who are interested, there are many sources to explore in this area including Di Scipio [5], Overholt [6], and Kim [7]. Perhaps the most comprehensive survey on this topic is presented in Cathy Van Eck's 2013 book *Between Air and Electricity* [8] and on the associated website, www.microphonesandloudspeakers.com.

The compositions she discusses include seminal pieces by the likes of Alvin Lucier, Nicolas Collins, Karlheinz Stockhausen, Agostino Di Scipio, Cathy Van Eck, and others. Moreover, for many of the practitioners mentioned by Van Eck, live feedback phenomena are the primary sonic materials for much of their most significant artistic outputs. All of these artists use a variety of methods for generating, altering, controlling, or attenuating feedback. In the next section of this paper, we present a brief overview of a selection of such artistic works – ones that we feel encapsulate the existing techniques for the incorporation and aestheticization of live feedback in experimental performances. Following this, we will briefly discuss some features of the currently available virtual acoustic technologies. We then present our method for producing and controlling live feedback with a virtual acoustic system. This method involves temporarily manipulating the feedback cancellation paths of the virtual acoustics system with delay lines. Normally the cancellation signal path is used by the system for the suppression of any potential loop gain that exist between the systems' microphones and speakers. By delaying this signal, we destabilize the system and create feedback at frequencies related to the amount of delay. We can then instantaneously restabilize the system and suppresses the feedback be restoring the cancelling signal path to normal. Most importantly, this method shows how it is possible to modifying the acoustic characteristic of the performance space in order to produce different qualities of feedback within the space and the space's installed sound system.

2. PRIOR WORK

2.1 A Brief Survey of Feedback in Experimental Sound Performance Practices

Artists who use microphone and speaker loop gain feedback phenomena as their primary (sometimes exclusive) sonic materials will explore and manipulated the feedback frequencies – and the loudness of these frequencies – thus avoiding unintentional howls, by the use of one or more of the following:

- EQ band pass or notch filtering
- Dynamic processing with compression/limiters
- Frequency shifting
- Simple or complex phase or polarity inversion
- Physical gestures or motions, which, change or attenuate feedback
- Changing the geometry of loop gain paths in a performance space and/or instrument
- Using piezoelectric microphones rather than air microphones

These types of aestheticized feedback generation, control, and suppression processes can be found in the following pieces:

Steve Reich – *Pendulum Music* (1968), for three or more performers with three or more microphones and speakers. This is perhaps one of the best known early examples of a live feedback based sound work. The microphones are each released and set swinging above the speakers. The feedback frequencies that output from each microphone and speaker gain loop gradually become more sustained as the periodicity of each of the swinging microphone reduces [9].

Alvin Lucier – *Empty Vessels* (1997), an interactive installation. Several microphones – pointed into glass or ceramic vases – are placed along the wall of a performance space. Several speakers are situated across a room along the opposing wall, with each speaker facing one microphone. The feedback produced by the gain loops between each pair of microphone and speaker is kept from turning into piercing howls by a combination of careful positioning during set-up and audio limiting. Importantly, the frequencies produced are additionally colored by the resonance of each corresponding glass/ceramic vase and microphone pairing. As visitors to the installation move through the space, their movements cause subtle alterations to the air currents and reflection paths in the room, and thus cause changes in the frequencies of the various feedback states [10, 11].

Cathy Van Eyck – *Wings* (2008), for three performers with large foam boards, three microphones, and one loudspeaker. Three microphones are placed downstage in a performance space. A speaker is place upstage. The resulting gain loop feedback is altered as the performers move the foam boards in a prepared choreography in front of the microphones. The movement of the boards significantly changes the geometries of the stage/performance space and thus cause changes to the feedback frequencies. This feedback is further processed by computer software [12].

Lesley Flanigan – *Speaker Feedback Instruments*, an ongoing project since the early 2000's. Flanigan's instruments consists of various small diameter speaker cones embedded in small portable mounts. A several-inch long flexible wire with a contact mic at the top is attached to the mounts. Vibrations from the speaker are transferred through this wire. Additionally, due to the proximity of the contact microphone to the speaker, vibrations are – somewhat unusually – also picked up by the piezo through the air. By physically adjusting the flexible wire the frequency and quality of the feedback changes, or in the case of the air vibrations, can be increased or eliminated. Flanigan further alters the feedback output by additional audio effects processing [13].

Nicolas Collins – *Pea Soup* (1974, revised 2001-14) is a work for concert performance or installation requiring self-stabilizing analog circuitry, now modeled with software. A loop gain microphone and speaker combination begins to go into feedback. As the feedback builds up between a microphone and speaker, the circuit/software shifts the frequency of the feedback slightly, temporarily taming the it. This process then repeats, with the loop gain increasing at the new frequency. In live concert performance the feedback frequencies are additionally altered by instrumentalists who play pitches that can produce audible beating against it. The movements of the performers can also interact and change the feedback, while in installation versions of the piece, it is audience movements that alter the frequency and quality of the feedback [14].

2.2 Virtual Acoustic Systems

Through the use of real-time virtual acoustic and acoustic augmentation/correction systems, the reverberant conditions of any performance space has the potential to be radically altered. When using these systems, the audience and performers have the sense that they are hearing sounds in a space other than the actual or expected acoustic of the physical space they occupy. With these systems – in both commercial and academic settings – the simulations/auralizations that are created are likely to have the acoustic characteristics of a specific concert hall or room, or perhaps the acoustic characteristics of a religious temple, church or large cathedral. While these systems facilitate music, theatre, and other time-based art performances, they are likewise used in non-artistic research applications related to areas such as perception and cognition studies. They have also been integrated into a variety of training simulations [15]. Perhaps the most extensive investigation into the architecture of many of the typical virtual acoustic/acoustic augmentation systems and their feedback suppression methods can be found in a review paper by Mark A. Poletti [16]. Suffice to say that in the commercial sector, systems are available from companies such as Meyer [17], D&B Audio [18], Lexicon [19], Yamaha [20] and others. While, in the academic research sector, virtual acoustic systems have been developed – and continue to be developed – at institutions such as McGill University [21], Stanford University, and the University of Limerick [22].

All of these systems use microphones and speakers in close proximity and must find ways of eliminating any potential loop gain feedback situations. As Poletti and others discuss [23], techniques such as subtle frequency shifting, adaptive notch filtering, time variation etc. can be used to do this. The architecture and the signal paths of all such systems – the software and the systems' microphones and speakers – in theory, allow for the introduction of feedback into performances. However, such systems are in general very expensive and thus institutions – and in some cases the manufacturers themselves – may be understandably unwilling or unable to facilitate feedback based experimental performances safely, and without nullifying product warranties! Thus in order to explore live feedback phenomena with virtual acoustic systems without resorting to synthesized versions of feedback sounds [24, 25], one must use a system that is relatively inexpensive and flexible in its calibration and configuration.

3. METHODOLOGY

3.1 Feedback Generation and Suppression Process

For this study we used a version of the virtual acoustic systems as described by Abel et al. [4]. This system is easy to install/uninstall and calibrate, and can operate with a variety of commonly available microphones and speakers, requiring no specific proprietary hardware or software. The virtual acoustic auralizations are generated with low latency convolution reverberation. When running, musicians can interact and move freely in the virtual acoustics spaces and environments without the use of headphones or close microphones. While the system can operate with any number of speakers and microphones, for a medium sized room, four speakers with two omnidirectional microphones can create a satisfactorily immersive environment [22].

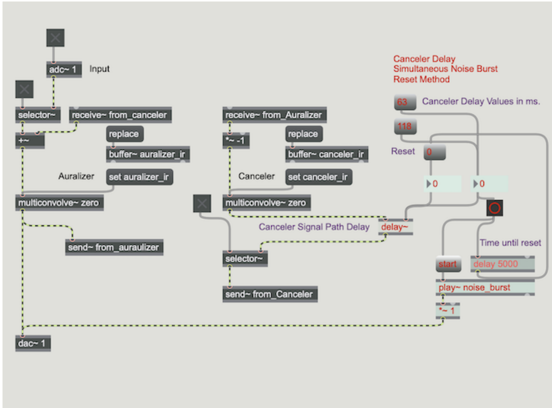

Figure 1. A possible Max/MSP implementation of Abel et al. including a variable length delay in the canceler signal path.

Figure 2. A minimal auralization system consisting of one microphone and speaker. Note that this system would be prone to feedback at frequencies associated with the direct path and first reflection (off the table).

Following calibration of the system, the feedback cancellation maintains stability as long as the geometries and gain structures between microphones and loudspeakers remain relatively unchanged. For example, the system can be destabilized by temporarily blocking the microphone speaker signal path by placing a hollow object such as a cup, drum, box etc., over the microphone. When this is done, similar to Lucier's *Empty Vessels*, the resulting feedback is colored by the resonance of these objects. Further to this, it is also reverberated by the virtual space at the time. By removing the object covering the microphone, the system re-stabilizes with any remaining feedback decaying. This decay continues to be colored by the reverberant characteristics of the virtual acoustic auralization currently running. Beyond this simple method for causing and then suppressing feedback with this virtual acoustic system, we are interested in demonstrating a more subtle method for inducing feedback. This method does not require a physical intervention and is similarly colored by the virtual acoustic auralization. It is achieved by inserting a

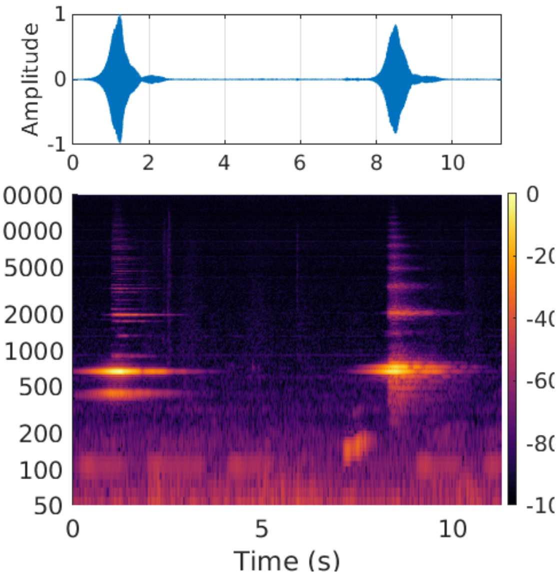

Figure 3. Spectrogram of *Palazzo Altemps* auralization system destabilized by a water glass covering the microphone.

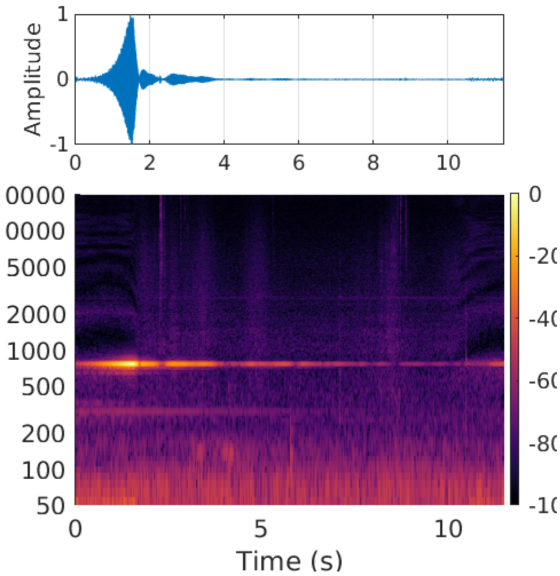

Figure 4. Spectrogram of *Hagia Sophia* auralization system destabilized by a water glass covering the microphone.

variable delay – as in Fig. 1 – into the feedback cancelling signal path, which is used for the elimination of loop gain feedback conditions between our virtual acoustic systems' microphones and speakers.

For clarity, we will demonstrate our delayed cancellation signal path method of feedback generation with a single speaker and microphone system as show in Fig. 2. With this simple configuration, we trigger a signal – a 300 millisecond pink noise burst – through the virtual acoustic system's speaker. Each time we trigger this noise burst we simultaneously change the amount by which the feedback canceling signal path is delayed. Thus, feedback tones are introduced whose frequencies are determined by how the virtual acoustic simulation is articulated by the noise burst and by the amount of time by which the cancelling signal is delayed. We then reset the delay to zero, restabilizing the feedback cancellation signal path. This causes the feedback to decay in a manner similar to how such frequencies would decay in the actual space as auralized by the virtual acoustic system.

3.2 Feedback Canceling Reverberator

Consider a reverberation system consisting of a single microphone $m(t)$, loudspeaker $l(t)$, and desired reverberation response $h(t)$. We would ideally like the loudspeaker signal to simply be the dry sound sources $d(t)$ processed by the desired auralization signal,

$$l(t) = d(t) * h(t)\,, \tag{1}$$

but we do not directly have access to the dry signals. Instead, we have the microphone signal which picks up the dry sources and feedback from the loudspeaker

$$m(t) = d(t) + l(t)\,. \tag{2}$$

Since the system exists in a room, both the dry source and loudspeaker signals also carry the acoustic impression of the room $g(t)$. It is not possible to know the room reverberation associated with the dry signals, but we can measure and estimate the room response between the loudspeakers and microphones. Thus, to form the loudspeaker signal from (1), we estimate the dry signal $\hat{d}(t)$ by the insertion of an optimal cancelling signal $c^*(t)$ which approximates the effect of the room $g(t)$

$$\hat{d}(t) = m(t) - c^*(t) * l(t), \quad c^*(t) \approx g(t) \tag{3}$$

If we delay the canceller signal by n ms,

$$c(t) = c^*(t - n)\,, \tag{4}$$

the canceller will be misaligned in time from the signal it is intended to cancel, causing a reduced in the amount of feedback suppression. We get feedback associated with the digitally lengthened microphone/loudspeaker paths filtered by $c(t)$ and $h(t)$.

4. RESULTS

As stated in the previous section, following calibration of the system, any change to the geometry or gain stages between the microphone and speaker of the virtual acoustic system has the potential to destabilize the system. Thus, in Fig. 3 we cover the microphone of the system with a paper cup until feedback is audible. [1] We then remove the paper

[1] Sound examples associated with Figs.3–6 can be online at https://ccrma.stanford.edu/~kermit/website/vafb.html.

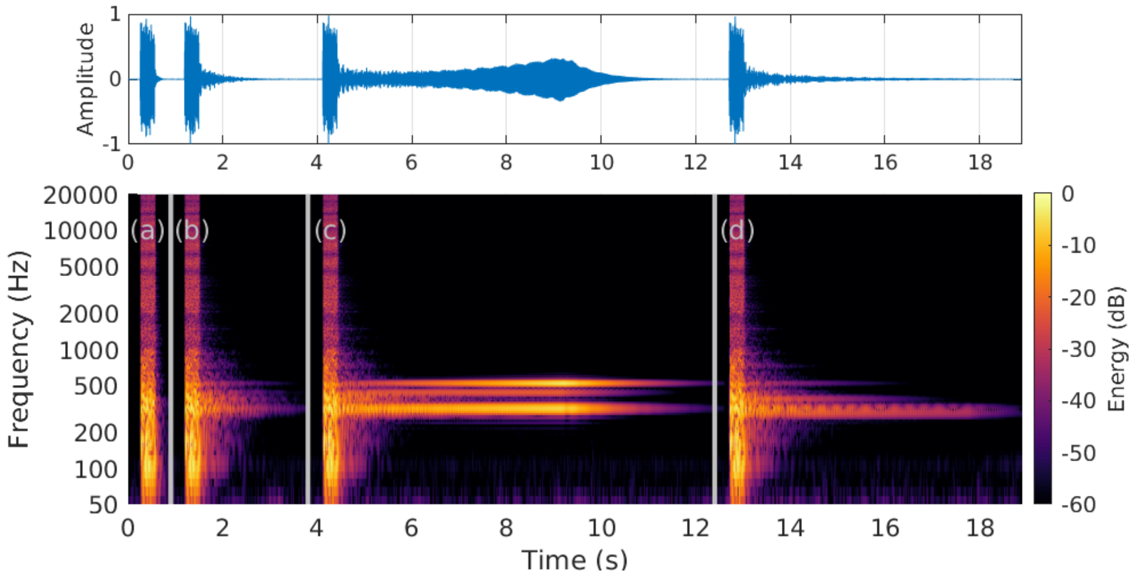

Figure 5. Spectrogram of (a) a 300ms pink noise burst, (b) in the acoustics of *Palazzo Altemps*, (c) with 1.4ms of canceler delay, and (d) with 2.7ms of canceler delay.

cup and the system restabilizes, with the feedback decaying into the virtual acoustic auralization. This process is then repeated using a different virtual acoustics in Fig. 4

Next, if we wish to induce feedback without the use of physical gestures we do the following. Here in Fig. 5 we see several iterations of a 300ms pink noise burst played through the virtual acoustic system's speaker. At (a) we see the pink noise burst with no auralization running. Next, at (b), we see the same pink noise burst triggered through this speaker while it is also diffusing a simulation/auralization of a virtual acoustic environment, that of a small Roman church located in the Palazzo Altemps. With (c), the pink noise burst is triggered, now with the virtual acoustic feedback cancelling signal path delayed by 1.4ms. As one would expect, feedback begins to emerge. Five seconds after the noise burst is triggered, the delay of the feedback cancellation path is reset to zero and the system restabilizes. Finally at (d), we repeat the triggering of a noise burst as the cancellation signal path is delayed by 2.7ms. Different feedback frequencies and colorations occur to those that with the shorter delay time. Again, five seconds after the noise burst is triggered, the delayed feedback cancellation signal is reset to zero and the system restabilizes.

In Fig. 6 we change the acoustic simulation to create an auralization of a different space, that of the Hagia Sophia in Istanbul, and repeat all of the previous steps. With this auralization there is a much longer T_{60} with a significantly darker timbre. Thus, it requires more time for feedback to emerge and become audible as we adjust the feedback cancellation signal path. And so, as we trigger the noise burst iterations while setting cancellation signal path delay time, we wait for nine seconds before resetting the delay to zero. We can see that at (a) the pink noise burst triggered with no auralization running on the virtual acoustic system. Next at (b) the pink noise burst is triggered in the virtual acoustic of the Hagia Sophia. Following this at (c), the pink noise burst is triggered with the cancellation signal path of the system delayed by 1.4ms, this being reset to zero after nine seconds. Finally at (d), the pink noise burst is triggered again with the cancellation signal path being delayed by 2.7ms, and resetting to zero after nine seconds.

The audible feedback in (c) and (d) of both Fig. 5 and Fig. 6 is a product of how the pink noise burst is articulated by the virtual acoustic simulation and by the amount that the feedback cancelling signal was delayed. Further, as the noise burst is triggered, the same feedback frequencies will occur if the same delay time is applied to the feedback cancellation path for that auralization. As the system resets the feedback decays into virtual acoustic similar to how such frequencies might be expected to decay in the actual space. In virtual and real spaces with longer T_{60}'s this decay will of course take longer too. These examples are illustrative if a little simple and reductive. For an example of the incorporation of our cancellation signal path delay method in an extended live performance, please see the documentation of a 2019 multimedia work: *Double Feature or The Bard Cheek Takes the Night Shift at the Piano*, which you can view on the same web page as the sound examples.

In this work various instances of the cancellation path delay method are demonstrated, again using a single microphone and speaker system. This time, the virtual acoustics system is placed and calibrated inside of a Disklavier. The sounds which were not made by the Disklavier, the other melodic piano recordings, or by the vocal sounds (sampled from the relatively dry soundtrack of the film version of Samuel Beckett's *Rough for Theatre 1*), are the result of virtual acoustic auralizations or the application of our cancellation signal path delay method [26]. We further

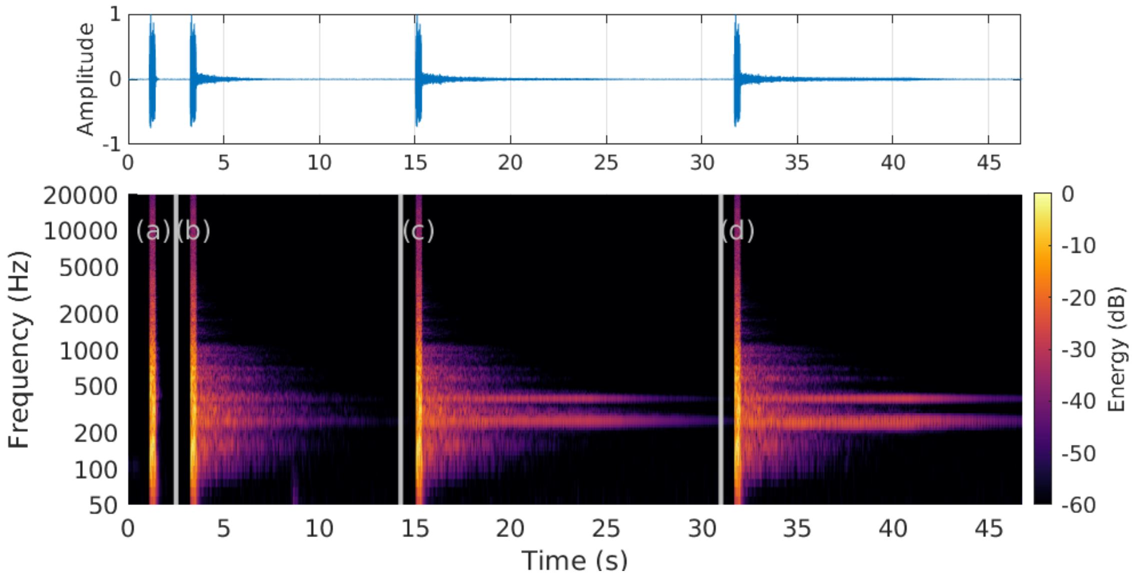

Figure 6. Spectrogram of (a) a 300ms pink noise burst, (b) in the acoustics of *Hagia Sophia*, (c) with 1.4ms of canceler delay, and (d) with 2.7ms of canceler delay.

Figure 7. Still from *Double Feature*. Note the single microphone/single speaker auaralization located within the Disklavier (in the lower left corner).

show off our system (for musical reasons) by using reversed impulse responses in the auralization system and using pitchshift processing on the input signal. In particular, from the beginning of the piece until 6:14, the results of the cancellation signal path delay method can be heard as two different virtual acoustics are crossfaded back and forth. Later, from 10:40 until 14:09 the cancellation path delay method is used extensively on a single auralization.

5. CONCLUSIONS AND FUTURE WORK

In this paper we demonstrated a novel method for incorporating live acoustic feedback into experimental sound performances using a modified virtual acoustic system. With this technology, it is possible to produce a variety of feedback frequencies and coloration. By destabilizing the virtual acoustic system in two ways, a variety of feedback frequencies that are colored by the acoustic characteristics of the virtual space became audible. In the first instance, we temporarily cover the microphone of our system with a resonator until the feedback begin. When the microphone is then uncovered, the system restabilizes and the feedback decays. In the second instance, we introduce a variable delay into the feedback cancellation signal path of a virtual acoustic system. By delaying the the cancellation signal, we generate a variety of feedback tones. These frequencies are also colored by how the virtual acoustic is articulated and the reverberate characteristics of the virtual acoustic auralization. We are then able to suppress these feedback tones by resetting the delay time to zero. Although this can all be achieved using readily available microphones, speakers, and software, it is now important to create a standalone and more user friendly application in order to make some aspects of the processes available to other artists. Finally, this paper only briefly mentions the other possible processing that can be introduced in combination with our method for delaying the virtual acoustic system's feedback cancelling signal. A longer discussion of our additional incorporation of creative filtering, reversals of virtual acoustic impulse responses, the use of dynamic virtual acoustic environments etc. will be covered in future papers and pieces.

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