Composing Embodied Sonic Play Experiences: Towards Acoustic Feedback Ecology

Akito van Troyer
MIT Media Lab
75 Amherst Street
Cambridge, MA, 02139
akito@media.mit.edu

ABSTRACT

Acoustic feedback controllers (AFCs) are typically applied to solve feedback problems evident in applications such as public address (PA) systems, hearing aids, and speech applications. Applying the techniques of AFCs to different contexts, such as musical performance, sound installations, and product design, presents a unique insight into the research of embodied sonic interfaces and environments. This paper presents techniques that use digital acoustic feedback control algorithms to augment the sonic properties of environments and discusses approaches to the design of sonically playful experiences that apply such techniques. Three experimental prototypes are described to illustrate how the techniques can be applied to versatile environments and continuous coupling of users' audible actions with sonically augmented environments. The knowledge obtained from these prototypes has led to the Acoustic Feedback Ecology System design patterns. The paper concludes with some future research directions based on the prototypes and proposes several other potentially useful applications ranging from musical performance to everyday contexts.

Keywords

Acoustic feedback control, sonic interaction design, interactive sonification, experiment, prototyping

1. MOTIVATIONS AND BACKGROUND

Traditionally, the relationships between acoustic feedback (also known as electro-acoustic feedback or audio feedback) and musicians, researchers, sound designers, and sound engineers have been mixed. When creating systems for public address (PA) system-based musical performance and interactive installations as well as electronic hearing aid and speech applications, unless the planners intentionally incorporate them as an integral part of the system, unwanted acoustic feedback sounds such as howling and screeching are subjects to be controlled to improve the performance quality [24, 13]. For example, in teleconferencing systems, the quality of audible communication degrades when acoustic feedback sounds are present, and engineers make effort to suppress such sounds using signal processing techniques such as gain reduction, phase modification, and frequency shifting/transposition [6]. In hearing aid systems, the reduction in the device size causes greater acoustic feedback between loudspeakers and microphone and prohibits the normal operation, and techniques such as adaptive filtering are exercised to increase the intelligibility of the incoming sound signals [16]. Even in musical performances where sound quality coming out from a PA system is of utmost importance, while proper sound design can help alleviate acoustic feedback present in PA systems, sound technicians also sometimes employ automatic acoustic feedback cancellation methods such as prediction-error-method-based acoustic feedback cancellation [23]. The deployment of such AFC methods prevents normally very loud and unpleasant howling sounds and provides optimal musical signal experience to the audience.

Acoustic feedback is also an inspirational source of achieving a rich textural palette of sounds in creative works. In popular music, rock guitarists such as Jimi Hendrix often make use of feedback that emerges between a guitar pickup and an amplifier to create distortion and special effects [19, 21]. When such technique is appropriately executed, the feedback allows strings on the electric guitar to vibrate and a note to be sustained indefinitely. We also find many example experimental compositions that incorporate acoustic feedback. One of the early composers who extensively used feedback in his work was David Tudor [2]. The "no input" electronic circuit design used in his pieces such as *Untitled* were arranged in a self-governing analog feedback loop system to create aspects of performance unpredictable to the performers and have them "discover" the performance in real time [10, 25]. Other notable early composers who used feedback in their work are numerous and we would like to direct readers to [19].

More recently, musicians and researchers have been incorporating acoustic feedback mechanisms in interactive installation systems and new musical interfaces. The *Audible Eco-Systemic Interface* (AESI) project by Di Scipio [3], *SD/OS (dirac)* by Sanfilippo [18], and feed-drum by Michelangelo Lupone [12] demonstrate techniques for establishing sonic couplings of environment, audiences' audible gestures, and a machine using acoustic feedback to create musical systems that spontaneously and aesthetically react to users' gestures. The electronic pipe instrument and Laptap projects [9, 8] as well as feedback control of acoustic musical instruments by Berdahl et al. [1] demonstrate practical approaches in creating new musical instruments using acoustic feedback. These projects focus on the creation of environments in which acoustic feedback can be effectively controlled so that the users can produce consistent sonic results.

Sonic interaction design (SID) demonstrates a promising study field to address human sound perception in interactive contexts and also lead us to think about designing effective interactive systems that involve acoustic feedback.

NIME'14, June 30 – July 03, 2014, Goldsmiths, University of London, UK.

One of the central investigation of SID is on the role that embodied action and sound perception play and relationships between them. Some SID researchers examine how users' action can be guided by sound and how the sound generated by the environment in a real-time process with continuous feedback in augmented everyday context affects sonic experiences [5, 15]. For instance, in the *Sound of Touch*, by Merrill and Raffle, a hand-held wand with sound recording and playback capability is continuously filtered by the acoustic interaction with the material being touched using digital convolution technique [14]. Almost all creative sound works mentioned in previous paragraph also feature the same unceasing sonic feedback, creating unique interactions between human, machine, and environment.

2. EXPERIMENTAL PROTOTYPES

Many existing programming languages for interactive music systems and multimedia such as Pure Data, Max/MSP, and Supercollider provide solutions for prototyping AFC algorithms. The basic Unit Generators (UGens), audio generation and processing components of the synthesis engine, natively provided by these languages enable building elementary AFCs to varying degrees. Because of the number of available UGens in the language that allowed us to rapidly prototype AFC algorithms, we chose to use Supercollider for the prototypes. The three prototypes, called VibroDome, WavTop, and Feedback Augmentation Toolkit (FATkit), explore and apply a mixture of different mediums, algorithms, and metaphors of interaction with a focus on creative interaction design and robustness.

In these prototypes, the type of AFC techniques used are strictly based on adaptive filtering, a filter that is designed to identify the feedback path and track its evolutions [24]. The adaptive filtering algorithm is used in these prototypes to minimize the error between the real and the estimated feedback signal to obtain the sound generated by the users and to apply digital signal processing techniques to it. Furthermore, in all of our experimental prototypes, the user-generated sound is used to produce sound in two ways: by directly applying signal processing techniques to augment its sound, and analyzing its acoustic properties to use the extracted features to control parameters of the synthesis engine.

2.1 VibroDome

What you see/feel is not like what you expect to hear...

This first design is inspired by the idea of transforming physical properties of a material surface to point out the incongruity in people's perception of vision, touch, and sound. It aims to betray people's expectation about a material. VibroDome consists of eight panels mounted on a quarter of a geodesic dome structure built with press-fitting medium density fiber (MDF). Various flat materials are framed using plywood which then are installed on the geodesic dome structure. Each panel incorporates a unique flat material such as glass, metal, and carpet. Each material is equipped with a contact mic and a transducer, both attached on the back side of the material. This configuration necessitates having a total of eight pairs of I/O channels feeding in and out of an audio computing device to augment sound properties for each material. Furthermore, each pair of signals is processed using an adaptive filtering technique to augment the tactile and sonic properties of each material when visitors play with the panel.

The sound generated from VibroDome in correspondence to visitors' gestures changes over time in a looping fashion, due to the programming instructions embedded in the synthesis engine, to perpetually stimulate the curiosity of visitors towards the presented materials. While visitors interact with the sculpture, this dynamic synthesis engine produces sound by arbitrarily exploiting and combining the aforementioned two signal processing methods with one condition: the amplitude of sounds generated by the transducers is constantly controlled by the amplitude of the reconstructed input sound captured by the contact microphones. Such configuration was used to correlate the user generated audible actions with their perception of augmented sound from the materials. Given this arrangement, some sections of the synthesis instruction utilize signal processing methods based on time delay and granularization while other sections generate sounds by applying pitch and spectral analyses on the input signal to generate sawtooth, formant, and white noise-based synthetic sounds.

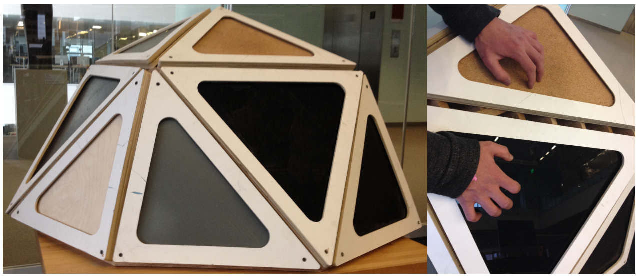

Figure 1: Left: VibroDome. Right: Interaction with VibroDome (scratching, hitting, and pressing).

2.2 WavTop

Control music with hand gestures above a laptop.

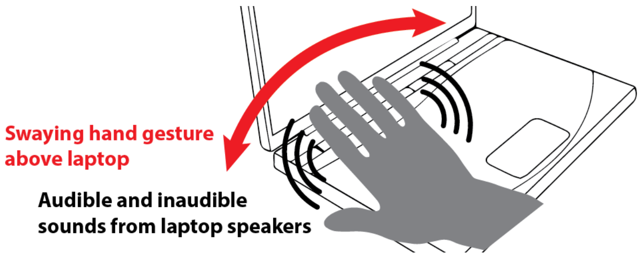

Figure 2: The WavTop interaction model.

This next prototype was inspired by projects that pair a speaker and a microphone to act as a sensor to detect the presence and gesture [7, 22, 17] as well as projects that take advantage of sound in inaudible range for designing musical applications [26]. While the previous works focus on analyzing the frequency shift and phase contents of the sound to determine the presence and gesture of the users, the WavTop system measures the intensity fluctuations of feedback sound in virtually inaudible range (18kHz to 22kHz) interrupted by a mid-air hand waving gesture above a laptop computer. The system produces frequency varying sine tone above inaudible range and then simply uses the Schmitt trigger [20] for thresholding fluctuating sound intensity to determine if the hand is present above laptop. The system then uses the measurement result to control another audible sound signal from the same speaker in real time (see Figure 2). This dual usage of speakers proved to work well and such implementation was possible due to deployment of the AFC algorithm in the signal processing chain.

Currently, the system can only detect slow moving hand gestures that are maximum 10 inches away from the speaker-microphone setup. This is because the system needs some time for the intensity of feedback sound to rise to a certain level. We also found that as long as audible sounds do not excessively interfere with the inaudible sounds used for the presence detection, the system can produce wide range of audible sounds. Because users are interacting with a set of a speaker and a microphone directly with their hand, the system gives an impression to the users that they are tangently touching the sound with their hands. WavTop demonstrates a potentially practical use of acoustic feedback in creative applications to turn anyone's laptop, mobile devices, and PA systems into musical controllers with mid-air hand and body gestures.

2.3 Feedback Augmentation Toolkit

Turn sonorous objects into interactive sonic entities.

The third prototype, called Feedback Augmentation Toolkit (FATkit), expands the previous two prototypes in the direction to generalize the system of AFC in the creative application contexts. In this iteration, we looked into ways to augment sonic properties of any sonorous objects with users' audible actions and explored the effect of directly producing electroacoustic sounds from a body of a musical instrument on music instrument players. FATkit consists of an audio amplifier (for output) / preamplifier (for input) box, a contact microphone, a transducer, audio cables, and double-sided stickers to quickly attach and remove the contact mic and transducer on any surface (see bottom right of Figure 3). Replaceable stickers allowed us to experiment with FATkit on various objects including tables, mobile devices, glass bottles, and plushies.

Figure 3: FATkit on a guitar. Bottom right: The basic parts of FATkit.

While FATkit can effectively be applied to almost any objects, we primarily experimented FATkit on a classical guitar to see if an AFC technique can be used to change the acoustic properties of traditional acoustic instruments and create unique playful experience for the musicians (See Figure 3). Since classical guitar already possess a rich source of musical timbres, we essentially focused on layering additional electroacoustic sounds on the soundboard to accompany the original guitar sound. We applied standard guitar effect unit such as delay, reverb, pitch shifting, and distortion, and the electroacoustic sound produced by the transducer adequately caught attentions of the players as they exhaustively experimented with extended techniques such scraping strings, tapping on the guitar body, and harmonics. This suggested us that embedding electronic sound production mechanism into the instrument body increases the physical connection to the generated sound and the continuously coupled sonic response that the players feel while playing the instrument affect their musical experience.

3. ACOUSTIC FEEDBACK ECOLOGY

These series of experimental prototypes led us to think about extracting common design patterns and how to harness the power of AFC techniques to apply to various sound related creative works and product designs in meaningful and playful ways. Our logical consequence in this direction is to propose a general framework that utilizes AFC techniques to create interactions among, human, environment, and a machine. We call this framework Acoustic Feedback Ecology System (AFES) and the system diagram is illustrated in Figure 4. In this system, a microphone collects acoustic signals from both users' audible actions and sound generated by a loudspeaker resulting in signal *s[t]*. Since the system knows what was outputted from the speaker indicated as *x[t]*, it also uses this signal to refine the parameters of the adaptive filter signal that we call *y[t]*. The filter is then applied to *s[t]* to estimate the audible actions generated by the users that is denoted as *e[t]*. The estimated signal *e[t]* can then be used in two different ways. One is to analyze the audio features of the signal to produce sound using custom synthesizers. Another is to directly apply audio effects to the estimated signal to alter its properties.

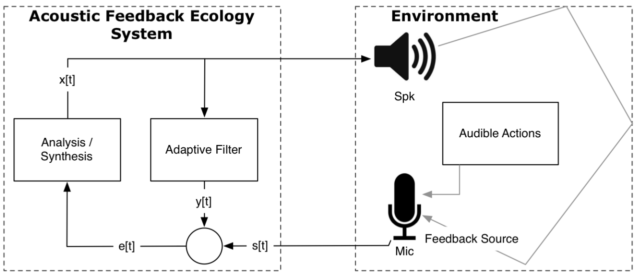

Figure 4: The Block diagram of AFES.

Designing interactive applications using the AFES system suggests unique approaches in engaging users in embodied playful experience. For example, the facilities for the system to continuously generate sound in correspondance to users' audible actions and to augment the sonic properties of tangible sonorous objects can introduce incongruities in the users' senses. Sensory incongruities can elicit the feelings of suprise from people who interacts with objects and provide out of ordinary pleasant interactive experiences to them [11]. As demonstrated with VibroDome, we believe that making use of the AFES system to create conflicting sensory experience can lead to users' playful interactive experience.

We also believe that using the AFES system to design and embed electroacoustic sound production mechanism into the body of musical instrument increases the physical connection to the generated sound, and the continuously coupled sonic and tactile responses that the players feel while playing the instrument can affect their musical experience. As suggested by Essl and O'Modhhrain [4], integrated sensorimotor experiences and their ongoing support by repeated interaction are important factors in the playability of a musical instrument. As demonstrated with both WavTop and FATkit, the musical instruments and controllers designed using the AFES system can have immediate and steady tactile and auditory feedback to the players' audible actions. Furthermore, the system can be instrumental in designing interactive musical experience under well-defined physical constraints.

4. CONCLUSION

Three experimental prototypes in this paper have provided understandings of the AFC techniques in the context of designing sound-based creative interactive applications. We found that AFC techniques can be deployed both to create continuous sonic interaction with users' audible gestures and detect the presence and gesture of the users to further be used as a control source for interaction. Furthermore, such findings directed us to framework a preliminary design pattern called the Acoustic Feedback Ecology System. However, further fine tuning of the acoustic feedback cancellation algorithm are still required. We plan to make this happen in several ways to create better filtering system including: modeling the acoustic properties of environment on the fly; trying out different AFC algorithms; and incorporating machine learning techniques. Currently, the software system runs on a computer capable of running Supercollider, but to further enable the area of applications, we hope to integrate the better system presented in this paper on embedded audio computing devices so that it can be applied to more versatile environments including music performance and installation as well as everyday contexts such as musical augmentation of everyday object sounds and interactive objects that work with audible gesture. We also hope that materials provided in this paper will enable a wave of AFC-based sonic applications beyond traditional domains in which AFC is primarily used.

5. ACKNOWLEDGMENTS

The author would like to acknowledge the support from people to this research including Muriel R. Cooper Professor Tod Machover, Rebecca Kleinberger, and Arthur Petron.

6. REFERENCES

[1] E. Berdahl, J. O. Smith III, and G. Niemeyer. Feedback control of acoustic musical instruments: Collocated control using physical analogs. *The Journal of the Acoustical Society of America*, 131(1):963–973, 2012.

[2] C. Burns. Designing for emergent behavior: a john cage realization. In *Proc. ICMC*, 2004.

[3] A. Di Scipio. Sound is the interface: From interactive to ecosystemic signal processing. *Organised Sound*, 8(3):269–277, 2003.

[4] G. Essl and S. O'modhrain. An enactive approach to the design of new tangible musical instruments. *Organised sound*, 11(03):285–296, 2006.

[5] K. Franinović and S. Serafin. *Sonic Interaction Design*. The MIT Press, 2013.

[6] M. Guo et al. Analysis of acoustic feedback/echo cancellation in multiple-microphone and single-loudspeaker systems using a power transfer function method. *Signal Processing, IEEE Transactions on*, 59(12):5774–5788, 2011.

[7] S. Gupta et al. Soundwave: using the doppler effect to sense gestures. In *Proceedings of the 2012 ACM annual conference on Human Factors in Computing Systems*, pages 1911–1914. ACM, 2012.

[8] D. R. Hong and W. S. Yeo. Laptap: Laptop Computer as a Musical Instrument using Audio Feedback. In *In Proceedings of the International Conference on New Interfaces for Musical Expression (NIME)*, pages 233–236, 2013.

[9] S. Kim and W. S. Yeo. Electronic Pipe Instrument using Audio Feedback. In *In Proceedings of the 9th Sound and Music Computing Conference*, 2012.

[10] R. Kuivila. Open Sources: Words, Circuits and the Notation-Realization Relation in the Music of David Tudor. *Leonardo Music Journal*, 14:17–23, 2004.

[11] G. D. Ludden, H. N. Schifferstein, and P. Hekkert. Surprise as a design strategy. *Design Issues*, 24(2):28–38, 2008.

[12] M. Lupone and L. Seno. Gran cassa and the adaptive instrument feed-drum. In R. Kronland-Martinet, T. Voinier, and S. Ystad, editors, *Computer Music Modeling and Retrieval*, volume 3902 of *Lecture Notes in Computer Science*, pages 149–163. Springer Berlin Heidelberg, 2006.

[13] J. A. Maxwell and P. M. Zurek. Reducing acoustic feedback in hearing aids. *Speech and Audio Processing, IEEE Transactions on*, 3(4):304–313, 1995.

[14] D. Merrill, H. Raffle, and R. Aimi. The sound of touch: Physical manipulation of digital sound. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '08, pages 739–742, New York, NY, USA, 2008. ACM.

[15] S. D. Monache, P. Polotti, and D. Rocchesso. A toolkit for explorations in sonic interaction design. In *Proceedings of the 5th Audio Mostly Conference: A Conference on Interaction with Sound*, page 1. ACM, 2010.

[16] C. R. C. Nakagawa, S. Nordholm, and W.-Y. Yan. Dual microphone solution for acoustic feedback cancellation for assistive listening. In *Acoustics, Speech and Signal Processing (ICASSP), 2012 IEEE International Conference on*, pages 149–152. IEEE, 2012.

[17] M. Ono, B. Shizuki, and J. Tanaka. Touch & activate: adding interactivity to existing objects using active acoustic sensing. In *Proceedings of the 26th annual ACM symposium on User interface software and technology*, pages 31–40. ACM, 2013.

[18] D. Sanfilippo. Turning Perturbation Into Emergent Sound, and Sound into Perturbation. *To appear in the INTERFERENCE / A Journal of Audio Culture*, 2014.

[19] D. Sanfilippo and A. Valle. Feedback systems: An analytical framework. *Computer Music Journal*, 37(2):12–27, 2013.

[20] O. H. Schmitt. A thermionic trigger. *Journal of Scientific Instruments*, 15(1):24, 1938.

[21] C. R. Sullivan. Extending the Karplus-Strong algorithm to synthesize electric guitar timbres with distortion and feedback. *Computer Music Journal*, 14(3):26–37, 1990.

[22] S. P. Tarzia et al. Sonar-based measurement of user presence and attention. In *Proceedings of the 11th international conference on Ubiquitous computing*, pages 89–92. ACM, 2009.

[23] T. Van Waterschoot and M. Moonen. Adaptive feedback cancellation for audio applications. *Signal Processing*, 89(11):2185–2201, 2009.

[24] T. van Waterschoot and M. Moonen. Fifty years of acoustic feedback control: state of the art and future challenges. *Proceedings of the IEEE*, 99(2):288–327, 2011.

[25] B. Viola. David Tudor: The Delicate Art of Falling. *Leonardo Music Journal*, 14:49–56, 2004.

[26] W. S. Yeo, K. Kim, S. Kim, and J.-S. Lee. TAPIR sound as a new medium for music. *Leonardo Music Journal*, 22:49–51, 2012.