The Feedback Mop Cello: An Instrument for Interacting with Acoustic Feedback Loops

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ABSTRACT

This paper presents the Feedback Mop Cello, an instrument integrating acoustic feedback loops generated through a microphone and loudspeaker in combination with a control interface inspired by the cello. Current paradigms of interaction with feedback instruments are based around ideas of negotiation with autonomous systems rather than control. We explore the possibility of integration of negotiated and controlled elements through a design focused on isolating the acoustic feedback loop signal path from the signal path to which sound processing is applied. We focus on three musical parameters of timbre, pitch, and dynamics. We present timbre as a parameter to mainly be negotiated within the feedback loop, while pitch and dynamics are parameters that can be explicitly controlled through the interface. An approach is taken to minimize components within the feedback loop in order to foreground the choice of the loudspeaker as an integral part of the instrument's sound. A preliminary user study is carried out involving five semi-professional musicians, focusing on their reflection regarding their interaction with the acoustic feedback loop.

Author Keywords

Acoustic Feedback, Microphone, Loudspeaker, Interaction

CCS Concepts

•Applied computing → Sound and music computing; Performing arts; •Human-centered computing → *Interaction devices;*

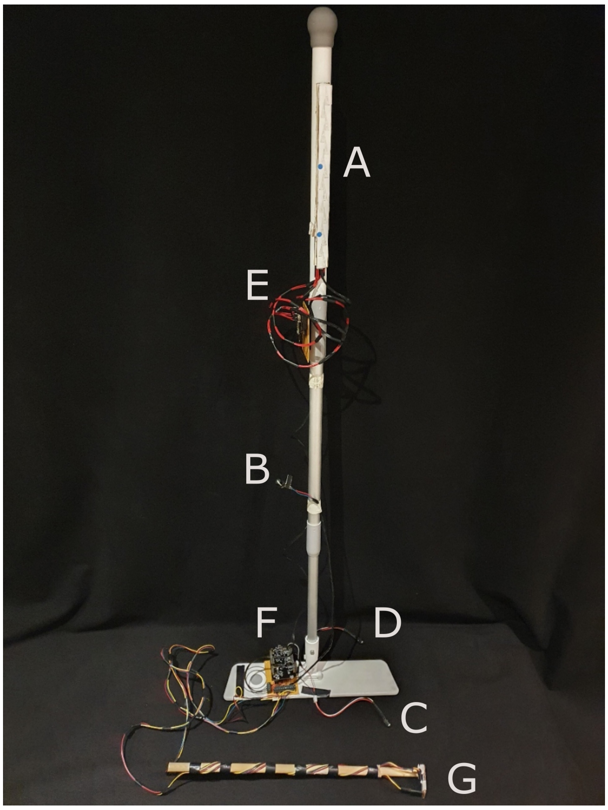

Figure 1: The Feedback Mop Cello. Visible are capacitive sensors (A), gain control (B), feedback loudspeaker jack (C), output loudspeaker jack (D), Trill Craft (E), Bela (F), and bow (G).

1. INTRODUCTION

The Feedback Mop Cello (Figure 1) is a prototype instrument based on a feedback loop generated between microphone and loudspeaker combinations. We aim to explore two approaches toward interaction with music systems, a control paradigm, common in digital musical instruments, and a negotiation paradigm through which interaction with feedback loops is increasingly framed. Applying these approaches to separate sections of the signal path, we are able to minimize the components involved in the feedback loop, enabling us to present choice of the loudspeaker as integral to the sonic characteristics of the feedback and instrument itself.

The microphone and loudspeaker are embedded in a sensor-based control interface through which gesture-to-sound mappings are grounded in a cello metaphor. The minimization of components in the feedback loop enables frugality of design and implementation, with the control interface constructed around a floor mop and wooden stick.[1]

[1]Design documents and code: https://github.com/Hughav92/feedback_mop_cello.git
Video Demonstration: https://mct-master.github.io/interactive-music/2022/12/08/hughav-feedback-mop-cello.html

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2. RELATED WORK

Acoustic feedback is a positive feedback effect in which the output of an amplified audio system is passed to the input and reamplified. The result is a sustained, pitched tone, with the perceptual qualities of the sound being highly unpredictable due to the non-linear nature of audio feedback systems [19]. Early adopters of musical acoustic feedback include rock guitarists of the mid-20th century [19], who, for example, attempted to exert control over parameters such as pitch [5]. Composers of the avant-garde music of the mid-20th century explored possibilities offered by feedback loops generated through microphone and loudspeaker combinations [16], [18], [21].

Sanfilippo and Valle's framework offers several insights regarding interaction with musical feedback systems [19]. Firstly, performers often prefer improvisatory modes of performance. Moreover, the system itself can display a degree of autonomy. This results in a non-hierarchical relationship between performer and system. In relation to feedback instruments, Magnusson et al. note that performers tend to view the relationship as a distributed agency [14]. This is seen as a desired element, with performers rejecting ideas of control over instruments and placing emphasis on dialogue and negotiation.

For digital instrument designers, this results in a different challenge to non-feedback instruments. Instead of designing interactions which work towards providing intimate control and embodiment, building towards expressive playing [6], [7], designers of feedback instruments define the terms of negotiated interaction. Eldridge et al. frame this in terms of cybernetic theory [4]. Johnston et al., refer to these two approaches as instrumental and conversational (with a midpoint of ornamental), and note that designing for a conversational approach can be difficult [12].

Electro-acoustic feedback instrument luthiers commonly design mechanical systems to constrain feedback potential. The Guitar Feedback Instrument makes use of actuators to exert pressure on a position on the fretboard to enable precise exploration of timbre [15]. Krzysztof Cybulski's Feedback Synth[2] mechanically moves a loudspeaker into positions relative to a microphone to hit defined pitches. These systems often focus on controlled interaction with a single musical parameter due to the complex relationship between states of the system and musical parameters.

Various approaches include inserting objects within the feedback loop. For example, Bowers and Haas' *Hybrid Resonant Assemblages* place focus upon the physical and sonic materiality of resonating objects within the feedback loop [2]. Recently, there has been a growing movement of Self-Resonating vibrotactile feedback Instruments (SRIs) [4]. These consist of augmenting a resonating body (often an acoustic instrument) with an actuator and a pickup transducer. SRIs employing an acoustic instrument include the Feedback Lap Steel [9], the Feedback Resonating Double Bass [13], the Self-Resonating Feedback Cello [3], the Halldorophone [23], and the Feedback Trombone [20]. These often position the primary site of interaction on the resonant body. This allows the control interface instrument to be leveraged to carry over existing expressive instrumental technique, which can interact with the autonomous nature of the feedback loop through mechanisms as simple as triggering it into action [19]. As noted by Eldridge et al., these instruments demonstrate the shift of the traditional control paradigm towards one of negotiation [4]. They additionally note that this results in quite a high technical barrier to performance. Moreover, the technical knowledge required to augment an instrument to leverage its resonances and the financial outlay to acquire a 'spare' instrument to augment invasively can be relatively high.

[2]https://krzysztofcybulski.com/feedbacksynth.php

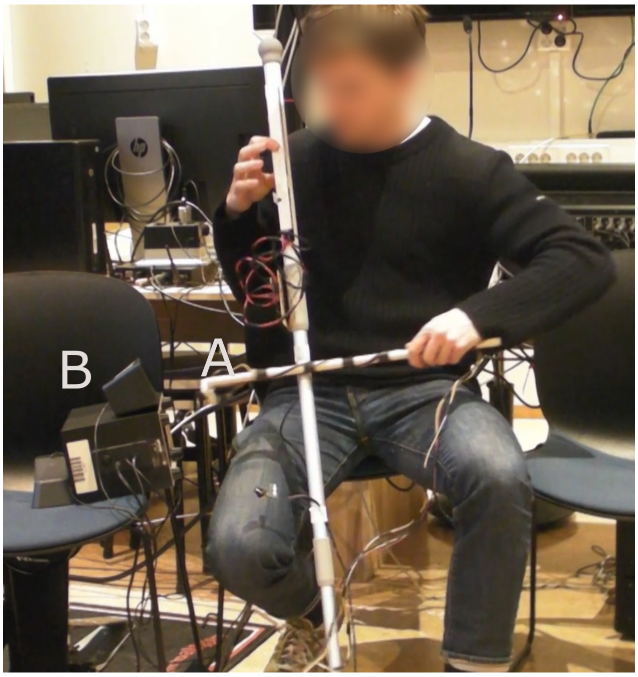

Figure 2: Performing with the instrument, negotiating timbre through the relative distance between microphone (A), and feedback loudspeaker (B).

Inserting a resonating body into the feedback loop raises questions about using microphones and loudspeakers as musical instruments. Cathy van Eck contends that an interacting approach that underlies these devices' use as musical instruments, requiring negotiation of their resonances and resistances [21]. She notes that the physical construction of these components plays a significant role in the sound of the feedback loop, however, each additional component added acts as a filter. Therefore, the fewer components added to the feedback loop, the more decisive the choice of microphone and loudspeaker become. With a large number of components, it is the sum of these that determines the instrument's sound. For SRIs employing microphones and loudspeakers, it is arguably the resonances of the instrument that is more determinant of the sonic qualities than these devices.

3. DESIGN AND IMPLEMENTATION

Our approach with the Feedback Mop Cello is centered on providing negotiated interaction framed through limitations provided through controlled interactions. We also aim to work towards a synthesis of negotiated and controlled interaction to enable expressive play and foreground the sound of the microphone and loudspeaker combination. This underlies six central design goals for the Feedback Mop Cello:

1. Intimate and expressive control of pitch and dynamics
2. *Negotiated* control of timbral parameters
3. Ability for customization of the loudspeaker to allow a considerable change in the sound palette
4. Minimization of components within the feedback loop that color the sound

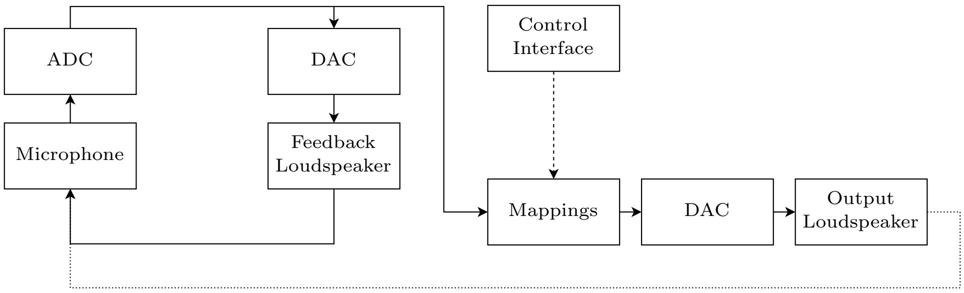

Figure 3: The feedback system. Audio signals are represented with solid lines, control signals with dashed lines. Dotted lines represent an optional signal path.

5. A relatively easy-to-build instrument with frugality as a core value

6. Low barrier to entry to begin performing with the instrument

To meet these goals, the instrument integrates a microphone and loudspeaker to create a feedback loop, combined with a sensor-based interface inspired by the cello. The prototype control interface was assembled using easily available and reusable materials. In view of this, it can be seen as a form of infra-instrument [1].

The microphone is mounted on the tip of a stick and drawn across a mop while directed towards a loudspeaker next to the performer, visible in Figure 2. This configuration enables the exploration of the timbral space of the instrument, serving as a negotiated interaction with the feedback loop. Several units split and process the feedback signal at the ADC. As the audio signal is no longer part of the feedback loop, traditional strategies are employed to map the sensor signals to audio signal processing parameters, working towards intimate and expressive control, focusing on pitch and dynamics. The processed signal is output to a second loudspeaker which is excluded from the feedback loop, as illustrated in Figure 3. Neither of the loudspeakers required by the system is embedded within the instrument and can be exchanged.

Fels et al. provide an approach towards achieving expressivity assuming transparency of gestural mappings as a predictor [8] . They contend transparency can be achieved through the use of metaphor, i.e. drawing on a commonly understood linkage between input gesture and sound output. This informed the design of the control interface, which we decided should take a form that enables a simplified "metaphorizing" of cello mappings. This was realized by focusing on two major components: 1.) a 'bow' constructed from a wooden stick (450 mm length x 15 mm diameter) with a cardboard front plate upon which a microphone and accelerometer are mounted, visible in Figure 4, and 2.) a 'body' comprising an ordinary floor mop augmented with a capacitive sensor array, shown in Figure 1. Figure 5 shows an overview of the electronic components and their location. Focusing on the three chosen parameters and their analogs on the acoustic cello, we decided to mainly situate pitch interaction through vertical motion along the top half of the body and timbre and dynamics as bow motion.

Pitch mappings originate from 15 custom-designed capacitive sensors (Figure 6), constructed from aluminum tape and affixed to the top of the mop handle. Each sensor increases in width to provide an increasing range of input values along its vertical axis. The signals captured by these sensors are mapped to a pitch-shifting unit based on two independent variable delay lines.[3] The primary mapping structure treats each sensor as a discrete input, determining if the input breaks a threshold and mapping each sensor to a discrete whole tone pitch-shift amount. Combinations of adjacent sensors provide the semitone pitch-shift amounts between each whole tone. This creates a simplified imitation of a cello string, although with a discrete rather than continuous mapping. Additionally, the difference between the current and previous sensor values is acquired, scaled, and summed to the pitch-shift value to emulate vibrato. The system uses an *MAX9814* electret microphone amplifier module, which has a very high level of gain and an omnidirectional polar pattern. This enables large bowing motions with the pitch of the feedback remaining constant, providing a stable pitch from which pitch-shifting can occur.

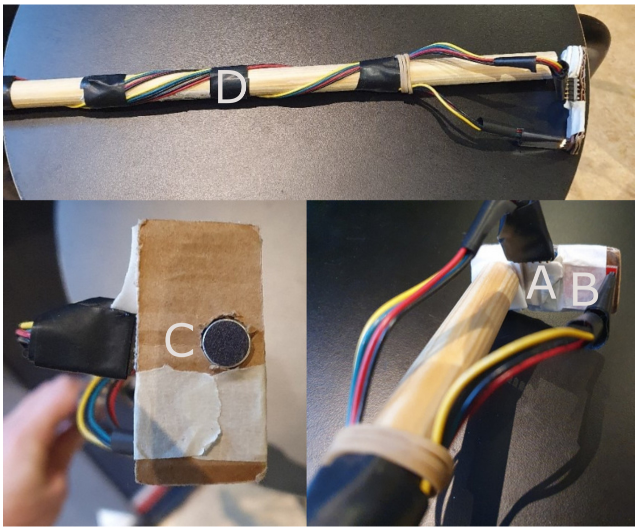

Figure 4: The bow component, with a microphone (A) and accelerometer (B), the microphone's diaphragm (C), exposed wiring (D).

A further sensor is an *ADXL337* 3-axis accelerometer (ACC) mounted below the microphone on the front plate of the bow. The ACC data controls the processed signal amplitude. From there, we compute the jerk, which is the first-order derivative of the ACC vector. The amplitude of the signal passed to the output loudspeaker is linearly

[3] The pitch-shifter is an adaptation of the variable delay line pitch-shifter included as an example in Pure Data vanilla: `http://www.pdpatchrepo.info/hurleur/pitchshifter~.pd` by user ClaudiusMaximus.

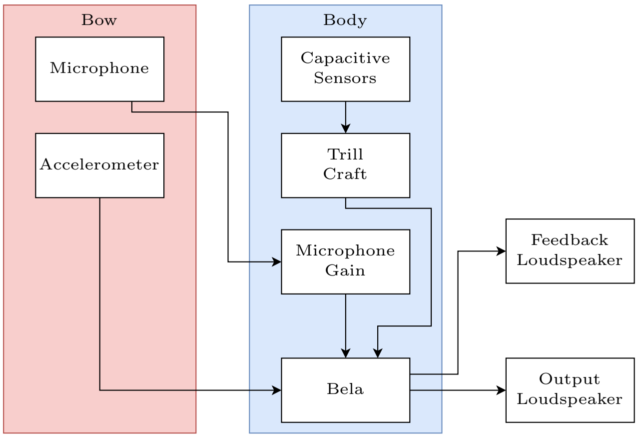

Figure 5: Block diagram of system components and relative placement.

Figure 6: The capacitive sensor array mounted on the top of the handle.

mapped to the overall jerk magnitude computed over the 3 axes, with higher jerk values mapped to higher amplitude values. This provides a sufficient signal for rapid bowing motions. To obtain usable input from slow bowing motions the wiring of the bow has been left exposed, resulting in constant fluctuations in ACC measurements. The amplitude values can never drop below a lower threshold, meaning that once the feedback loop has been triggered it is always audible, even when the bow is held still.

Additionally, the jerk data is mapped to the size of the window read from the delay line for one of the pitch-shifter units. Both units are passed the exact value of shift amount (in semitones) and have a default window size of 100 ms. After scaling the jerk signal, values over a threshold are inversely scaled to window values to a minimum of 10 ms for a single pitch-shifter. The output of the two pitch-shifters is summed, with the reduced window size pitch-shifter at approximately half the amplitude of the fixed window size pitch-shifter. The sudden reduction in window size has the effect of momentarily increasing the pitch of the second pitch-shifter. This emulates a cello bow's attack during a rapid bowing motion.

The instrument's software is written in Pure Data and run on a *Bela*[4] mounted on the mop base, as visible Figure 1. A *Trill Craft*[5] mounted below the sensor array is used to pre-process the capacitive sensors. Two mini-jack outputs are used to connect the feedback loudspeaker and the output loudspeaker. This enables the exchanging of loudspeakers.

4. DISCUSSION

We approach discussion of the Feedback Mop Cello from two perspectives:

1. Personal reflections relating to developing a method of performance.
2. An preliminary user study.

4.1 The Authors' Reflection

Performance setup developed into finding a position close to the loudspeaker where the feedback possessed a steady pitch. Several loudspeakers were tested, each providing its own steady pitch and timbral space. The choice of loudspeaker started to feel analogous to choice of instrument. At first, a small, portable, battery-powered speaker (ca. 1.7″ driver diameter) was used, which provided a high pitch. This was eventually exchanged with a desktop PC loudspeaker set comprising two tweeters (ca. 1.8″ driver diameter) and a sub-woofer (ca. 3.4″ driver diameter). Stacking one of the tweeters on the sub-woofer enables the creation of two feedback loops while playing, effectively extending pitch and timbral range. The most frequently used output loudspeaker was an installed speaker array consisting of two *Genelec 8030C* speakers and a *Genelec 7050B* sub-woofer.

The location of both the accelerometer and microphone on the bow provided an example of the way in which negotiated and controlled interaction can interact, as both timbre and pitch interaction occur within a single input gesture. The result is that if we aimed to perform a precise dynamic we would have to accept the resulting timbre. If we attempted to exert more control over one musical parameter, we would lose some control over the other. We found that balancing these interactions provided a rich playing experience, pointing towards the fact that complete isolation of individual interactions and the parameters they influence is not a sound strategy for achieving user engagement [11].

While playing the instrument, it became apparent that increasing the microphone gain creates a further feedback loop with the output loudspeakers, encompassing the entire instrument (see dotted line in Figure 5). This results in a playing experience with more unpredictabilities and negotiation. The final setup involved staged gain levels, where lower gain levels only create feedback from the feedback loudspeakers, while higher levels feedback with the output loudspeakers. This allows for switching between more controlled and more negotiated modes of interaction.

4.2 A Preliminary Study

The system was preliminarily evaluated by five semi-professional musicians. Our aim was to gain preliminary insight into how evaluators interact with the feedback components, and how this intersects with the instrument's presentation as a cello. Each evaluation session lasted approximately 30 minutes. The system was set up according to the method above. Four of the participants had no experience with

[4] https://bela.io/
[5] https://shop.bela.io/products/trill-craft

bowed stringed instruments. The fifth had formal training in classical violin. The evaluation sessions comprised a brief introduction to the instrument, a 10 minute period of free-play, and 10 tasks loosely inspired by the methodologies in [22], [17]. These focused the performance of specific dynamics, pitch, and timbral exercises, and interaction with the feedback loop. The sessions concluded with a further free-play period, followed by a semi-structured interview structured around seven prompt questions relating to musical parameters, interaction with the feedback loop, and controlled and negotiated interaction.

In reflection on pitch and dynamics, the participants felt that the instrument responded according to the expectations of their gestural inputs. However, the design of the capacitive sensors results in difficulties in reaching a determined pitch when not looking at the sensor strip due to the sensors being positioned in both a horizontal and vertical relationship to one another. They were able to reliably complete simple dynamics and pitch tasks so that they could learn to play a simple melody with some basic application of expressive dynamics by ear. Specific intervals above the steady pitch of the feedback could be reliably reproduced.

All participants emphasized that they felt more connected with a digital musical instrument modeled on the cello rather than with a feedback loop. According to one of the participants, the sound could have been synthesized and their playing experience would not have greatly altered. This points towards an insight provided by Eldridge et al. [4], where, referring to the Feedback Trombone [20], performers of self-resonating instruments express disappointment if the "wildness" of the feedback interaction is dialed down.

This was also reflected in the ways in which they interacted with the instrument. During free improvisations, the participants did not focus much on exploring the parameter possibilities offered by the spatial relationship between the microphone and loudspeaker. Instead, they explored the pitch and dynamic affordances of the control interface. They did not leverage interactions with the feedback loop, such as altering the microphone gain, and did not discover the ability to generate a second feedback loop with the output loudspeaker until they were informed of this possibility. Although prompted to think about ways in which the sound of the instrument could be changed, no participant mentioned the possibility of exchanging the feedback loudspeaker. The instrument's form and naming as a cello suggests its input modalities, with one participant noting that the feedback-centered interactions are not what a cello *does*. This aligns with Harrison et al.'s findings where guitarists preffered the familiarity of string-based inputs modalities [10]. The preoccupation with the cello interface was also reflected in their recommended improvements, mainly focused on making the instrument more cello-like, especially in the feedback from the violinist. This is in line with Fels et al.'s statement that a mapping metaphor that is not strictly adhered to can reduce transparency [8].

5. CONCLUSIONS

The Feedback Mop Cello provides insight into the relationship between controlled and negotiated interactions with acoustic feedback loops. Through an approach that isolates the audio signal path of the feedback loop within the system, individual musical parameters can be targeted for precision control through a sensor-based control interface mapped to parameters external to the feedback loop. This also enables the foregrounding of the sound of the microphone or loudspeaker components.

Additionally, the instrument leverages mappings grounded in metaphor to gain a step towards expressivity. We grounded our mappings explicitly in a metaphor of a pre-existing acoustic instrument for which negotiated interaction is not usually afforded central consideration. Evaluators of the instrument placed more emphasis on controlled parameters external to the feedback loop than the negotiated parameters within it, to the point that interaction with the feedback loop was sometimes ignored or treated as auxiliary. They recommended improvements focused on the quality of the mapping metaphors to the extent that negotiated interactions with the feedback loop would have to be further sublimated.

6. ETHICAL STANDARDS

All evaluation sessions involving human participants were carried out fully compliant with the ethical standards of the University of Oslo. All participants consented to the use of the audio and video recordings of their session in academic presentations and demonstrations of the system. All participants were informed of the fact that they would be identifiable in the video recordings and images taken from these and consented to their use in this manner. The electronics kit, the Bela, and Trill Craft were provided by the University of Oslo. There were no conflicts of interest in this project.

The prototype instrument was partially constructed with components recycled from previous projects. Upon disassembly of the system, the electronic components employed in its construction will be recycled for further projects. The mop will enter retirement at home, where it will fulfill its intended function of cleaning floors.

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