The halldorophone: The ongoing innovation of a cello-like drone instrument

Halldór Úlfarsson
EMuTe Lab, Department of Music
University of Sussex, UK
h.ulfarsson@sussex.ac.uk

Figure 1. A halldorophone completed in 2014.

ABSTRACT

This paper reports upon the process of innovation of a new instrument. The author has developed the halldorophone a new electroacoustic string instrument which makes use of positive feedback as a key element in generating its sound.

An important objective of the project has been to encourage its use by practicing musicians. After ten years of use, the halldorophone has a growing repertoire of works by prominent composers and performers. During the development of the instrument, the question has been asked: "why do musicians want to use this instrument?" and answers have been found through on-going (informal) user studies and feedback. As the project progresses, a picture emerges of what qualities have led to a culture of acceptance and use around this new instrument.

This paper describes the halldorophone and presents the rationale for its major design features and ergonomic choices, as they relate to the overarching objective of nurturing a culture of use and connects it to wider trends.

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Author Keywords

NIME, augmented string instrument, electromechanical actuation, drone, electroacoustic, string feedback.

CCS Concepts

- Human-centered computing~Auditory feedback
- Applied computing~Sound and music computing

1. INTRODUCTION

The halldorophone is predicated on feedback which is a phenomenon well explored by musicians since the 1960s when the experimental use of new electronic technologies coincided with a desire to innovate in the experimental and avant-garde music scenes of Europe and America [4][18].

Audio feedback is generated when sound picked up by a microphone (or comparable device) is passed to a speaker and then re-detected by the microphone. Due to the amplification in the system, a sustained, recursive signal flow is created; a positive feedback loop. This is familiar to most people as an unintended event during music shows but some musicians use this phenomena for their own ends. For Sabella, feedback is:

"an interesting case of a non-linear dynamic system, whose acoustic behaviour is highly unstable but partly controllable by the performer who, by manipulating the parameters of the relative positions of receiver and transmitter, can set up an interactive relationship with the system itself, guiding its evolution and in turn being guided by it." [17]

That quality of somewhat predictable but chaotic behaviour, can be desirable in musical performance as we will see.

2. RELATED WORK

Feedback is widely employed as a filtering or signal generator scheme in analogue and digital musical setups but it is unusual that it constitutes the *raison d'être* of the instrument, instances of both are discussed in this section with a bias towards systems containing strings.

2.1 Feedback Aesthetics

Within the practice of feedback in music, feedbacking strings (string vibration-to-pickup-to-amp-to-string) is a familiar method of colouring and generating sound, immortalized by Jimi Hendrix's feedbacking his Stratocaster against the amp stack at Woodstock in 1969. Other examples abound in popular music of electric guitar feedback: The Beatles' *I feel fine* (1964) is an early (perhaps first) recorded example of a prominent, standalone guitar feedback drone [19]. Later the full dirty, grit of the feedback sound is embraced and made prominent by Lou Reed on the album *Metal Machine Music* (1975), a practice continued by bands such as Sonic Youth as a major characteristic of their sound. It is worth mentioning Robert Fripp´s masterful application of feedback as colour in his guitar playing on Bowie's *Heroes* (1977). Feedback can be defined as a characteristic affordance of the electric guitar.

2.2 Feedback as Complementary Agency

The cybernetics of the 1950s and 60s inspired artists and musicians greatly and feedback became a prominent element in contemporary music too. *Wave Train, for piano resonances and feedback* by David Behrman (1968) applies the method of passing signal directly from string-to-pickup-to-speaker-to-string is used to induce feedback on a grand piano, with the score detailing the method of preparing the system and manipulating the feedback without being very specific about notes or frequencies, the musicality can be understood to be in the texture and dynamics of the feedbacking string system [1]. Sanfilippo and Valle describe the use of feedback in avant-garde and experimental music since the 1960s, suggesting that advances in cybernetics, acoustics and signal theory all served as inspiration for seminal works (compositions and installations) prominently utilizing the method [18]. They suggest a typological schema for musical feedback systems illustrated in Figure 2:

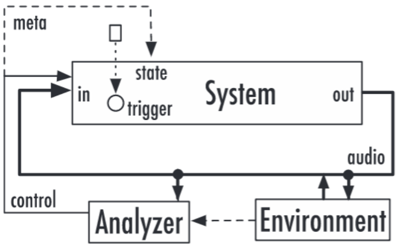

Figure 2. Feedback diagram.

A further discussion of their typology is beyond scope here but the diagram is brought to the reader's attention because of the "meta" path which is complementary to the main feedback loop. This is a profound addition to the basic loop of additive audio feedback as it points out the possible inclusions of refined, increasingly available, analytical cybernetic functions being added to the response of a feedbacking musical system. A recent example of a string instrument which is cybernetic at heart is Tom Davis' *Feral Cello* (2017) this musical system (or debatably, composition) is manifested as an augmented cello which is explicitly designed "to embody the idea that the musical instrument has agency as part of the creative process" [6] it does so by asserting itself in ways which can be seen as obstructive to the intent of the human performer via digitally crafted, reactive and feedbacking behaviours enforced, partly, by a listening machine agent. Taking a larger view, the last example of musicking seem to be on a trajectory traced by David Borgo:

"In the contemporary era not only is science evolving, as nonlinear, qualitative models and computation intensive analyses overtake older linear models that demand explicit solutions, but also music and the arts are evolving, as representational, individual-centered works are being overtaken by interactive, socially-oriented, nonlinear forms." [2]

Borgo´s conjecture is confirmed by the work of Candy, Edmonds and Johnson [11] in their identifying what they call a "conversational mode of interaction" in musical performance which they demonstrate to be attractive to musicians when engaging musical instruments capable of "talking back". In the case of their research these are virtual instruments with non-linear qualities which can, when compounded become somewhat complex, they describe the conversational mode of performance as:

"…seizing the initiative for a time to steer the conversation in a particular direction, then relinquishing control and allowing the virtual instrument to talk back and alter the musical trajectory in its own way." [11]

It is not far-fetched to say that here the instrument has a modicum of agency in the performance, it is "playing music" with the human. It is in this current wider trend, where machine-agency and complex systems complementing human expression are increasingly accepted, that the halldorophone, an instrument capable of "talking back" is finding acceptance.

2.3 Feedback Instruments

As we have seen, somewhat predictable but chaotic, cybernetic behaviour can be a desirable quality in a musical instrument and feedbacking strings is a technically easy way to get there. In recent examples of feedback string-instruments we see different strategies in organization and design.

Till Bowerman's *Half-closed-loop* is a performance setup or instrument, a study in improvising with positive feedback. The "half-closure" of the feedback loop is an enclosed string set on a slab of transducer-actuated wood, the vibrations of the string are detected and fed through digital and analogue filter stages to shape the signal in various ways before being played through the slab. What results is a reduction of string-feedback to an unstable oscillator / filter in an electro-acoustic looped signal path which is very sensitive to changes in the environment, including movements of "…the subliminal muscle tremor of the performer's hands, or just minimal posture changes - e.g., when turning a knob on the matrix mixer the system changes, resulting in a (small or more severe) variation of its sonic output." [5] Here the focus is on the temperamental, precariousness of the method as a modular component in a wider chain of signal processing, celebrating that distinct characteristic.

In Jiffer Harriman's *Feedback Lap Steel* [10] feedback is induced via tactile transducer directly coupled to the strings (via bridge), vibration of the strings is detected, processed, amplified and fed through the transducer closing the feedback loop. There is no discernible consideration for acoustics (other than those of the strings themselves) and so the user is implicitly lead to applying analogue or digital effects to the signal path for sculpting the timbre and behaviour of the system. The possibility of feedback is added onto an existing instrument as an extra affordance or effect, otherwise keeping the instrument's logic intact.

The *Feedback Harmonizer* (2009) and the *Feedback Harp* (2006) from the Folktek collective of electro acoustic luthiers are portable zither-like string instruments which induce string feedback with a variety of (unspecified) filters in the signal path to colour the sound. Folktek has a culture of loosely adhering to themed strands of instrument models while allowing each iteration to be distinct, coupled with a visual aesthetic pointing to the vernacular. The author deems these two instruments from Folktek to emphasise identity creation as part of the design effort.[1]

3. THE HALLDOROPHONE

The halldorophone, a cello like instrument developed by the author for over a decade, falls firmly in with the feedback based instruments listed above. In the halldorophone a positive feedback loop is induced in a coupled system of up to eight strings. The vibration of each string is detected with a dedicated pickup, the levels of which can be adjust before the mixed signals are amplified and sent to a speaker cone embedded in the back of the instrument. The speaker vibrates the whole system inducing positive feedback on the strings (the ones included in the mix). As such the halldorophone is a relatively simple system: the performer can play it with deterministic operations,

[1] www.folktek.com

but by adding gain to individual strings in the feedback loop the system becomes increasingly complex, possibly spinning out of control, or more interestingly, surfing along what Borgo calls “the balance point between stability and extreme turbulence.” [3] allowing for a “conversational” interaction of the sort described by Candy, Edmonds and Johnson [11].

To date, three halldorophones have been built and are now in common use, in addition to a diverse range of experiments that have contributed to the iterations of those instruments. The first one finalized in 2008, another in 2011 and the latest in 2014. There are two more instruments set for completion in 2018.

3.1 Rationale for the Project

This project started when the author was a visual artist in training. In considering many kinds of artefacts as potential material, there was one human technology that stood out: musical instruments as powerful cultural artefacts that carry a variety of meanings and values across social boundaries and are arguably at the cutting-edge of human technological skills at any given time [14]. Infiltrating the tradition of music with a new musical instrument became an exercise in understanding how cultural artefacts gain power.

String feedback was chosen as it seemed to have the right qualities: technically simple, with distinct and exciting characteristics for the performer and is an accepted technique, hovering at the margins of mainstream musical practice. As much a social experiment as musical instrument design, the author´s assumption was that an instrument with a clear identity and a mix of distinct, novel qualities, yet with familiar instrumental features would underpin success for a new instrument.

3.2 Early Experiments

It took a while to arrive at the conceptual and physical configuration of the halldorophone. Early experiments included a zither-like instrument (Figure 3) slung like an electric guitar to hang at the waist, leaving the hands free to change gain, manipulate movable bridges and work a whammy mechanism for vibrato.

Figure 3. Zither-like study from 2004.

Another configuration was an eight stringed, harp-like, “desktop module” as seen in Figure 4. Conceived of to be a sort of sound-generator and effect-box to be controlled via mixing desk or soundcard. It had pickups easily movable along the length of the string to affect which overtones to accentuate on individual strings as well as vibrato levers for individual strings.

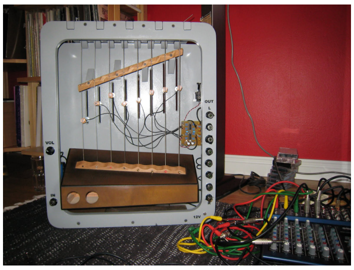

Figure 4. Harp-like study from 2007.

These and other, early studies where rejected as the author understood from user feedback that they were not particularly compelling, in terms of communicating an exciting narrative or a clear identity for a new instrument.

3.3 Identity

In an ongoing conversation with collaborators (most notably composer Timothy Page) on the qualities of early experiments, the focus began to move to the baroque strings as a point of reference. Referencing the classical strings is a tactical choice because of their association in the collective consciousness to virtuosic players and luthiers and the propensity of those instruments to occupy centre stage, all of which seemed like an asset to the identity of new instrument. Being cello-like also makes the instrument more relevant to numerous well-trained performers of the cello as it allows for the recycling of their playing skills.

Musically, a reference to a well-known, bowed string instrument (significantly bowed, having a vocabulary for sustained notes as opposed to picked, plucked or struck notes) suites the feedback affordance of sustaining notes. And an important consideration was for it to have a tuning length that affords a pleasantly low register (as feedback easily becomes grating at higher frequencies).

3.4 String Configuration and Ergonomics

Mimicking the major characteristics of a cello (upright, four strings, fretless fingerboard, bowable string configuration), the halldorophone also has four sympathetic strings running below the fingerboard (much like a viola d’amore or a barytone) which are not directly accessible for bowing or plucking but are rather electronically manipulated (most often via volume pedals). All strings have the potential to be (electronically) included in or excluded from the feedback loop.

3.5 Soundbox

The shape and proportions of the wooden soundbox were decided from an aesthetic point of view to give the instrument a clear visual identity. Acoustically the size of the box falls well short of the half-wavelength-rule given the suggested tuning: “...for good projection, a radiating surface should be greater in both dimensions than half the wavelength of the lowest frequency it is intended to project.” [9] Consequently the timbre of the box is slightly harsh and nasal in the inevitable comparison to a cello and its undersize is most likely a big contributor to the many wolf tones (spikes in frequency response) that tend to occur in halldorophones. Wolf tones are not a problem, as the instrument does not have defined criteria of quality for acoustic behaviour. The soundbox is intended to act more like filter than acoustic amplifier (as it does in traditional, purely acoustic string instruments), furthermore a soundbox between the speaker and strings makes for more interesting feedback. The inclusions of a soundbox widens the frequency bandwidth of an escalating drone and adds, an ill-definable, sense of body to the sound along with a more complex feedback due to the erratic acoustic response (wolf tones).

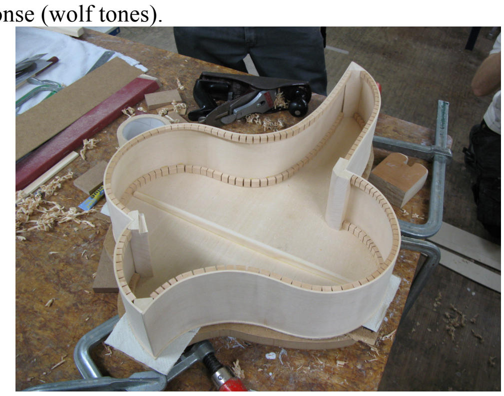

Figure 5. Soundbox construction.

The soundbox construction method, Figure 5, has been based on that of acoustic guitars: steam-bent sides connected with blocks in corners, back and top bonded to the sides with lining. The top has been braced with a few different patterns, mostly a variation on struts laid out in an x-shape. Choices of wood vary but adhere to the palette of "tonewoods" as widely recognized among guitar builders and in the guitar building literature (manuals). Construction design of the soundbox has mostly focused on making it structurally sound for the forces that act upon it while adhering to the precepts of acoustic guitar building (keeping it light and stiff).

3.6 Configuration of Electronics

Each string has a dedicated electro-magnetic pickup to allow for channel separation between them and therefore a detailed control of individual string levels in the feedbacking drone. See Figure 6. EM pickups are a good method of detecting string vibration for feedback as they generate signal directly from the moving mass of the string (which needs to have a ferromagnetic core, discussed below). Halldorophone pickups have previously been laboriously handcrafted by the author, but thankfully a company called Cycfi has marketed the Nu capsule; a single string pickup of good quality which is standard in halldorophones from now on.

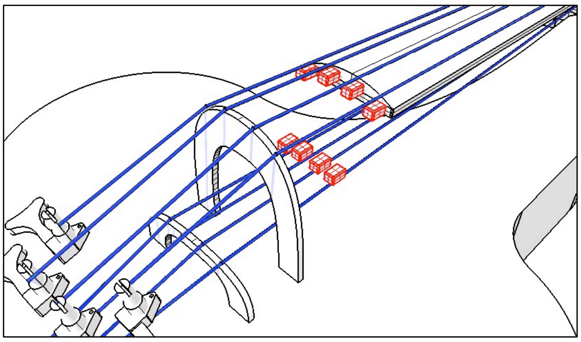

Figure 6. Pickup placement (in red).

The pickup signal is boosted and passed through a mixing stage where the player sets the levels before sending the mix to a 50w power amp driving a midrange speaker cone embedded in the back of the soundbox, completing the feedback loop. The ergonomics and affordances of the mixing stage have varied between versions. The current organization of the electronic controls is as follows: The volume level of the four upper strings is controlled with sliders, one for each string, placed on a bracket accessible to the right hand. See Figure 6.

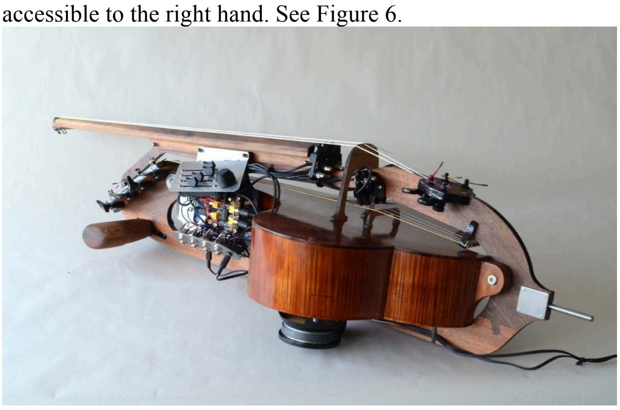

Figure 7. Halldorophone, side view.

The sympathetic strings have normalized line-level outputs and inputs, they are only included in the feedback if they are routed out and back in. The recommended way for the player is to set the levels of the lower set via routing to two stereo volume pedals (but can equally well be a mixing console or digital audio interface). The main strings signal cannot be routed externally in an attempt to keep things simple. There might be a return to all strings being externally routable in future versions, depending on further user feedback.

The trimmed signals are passed to the power amplifier, the master volume of which sits on the same panel (Figure 7) as the volume controllers for the upper set of strings. The layout of the electronic controls is familiar to anyone working with music equipment and close to that of any generic mixing console. In terms of ergonomics the main decision is to make them operable by the right (bowing hand) suggesting that the feedback can substitute bowing.

3.7 Stringing

The method of feedback (via the electromagnetic, coil-based pickup) requires the strings to have a ferromagnetic core for them to create magnetic fluctuation in the pickup to produce current. Daddario brand Helicore or Prelude electric-cello string sets have served well for the upper set, giving a bright, light sound. The lower set has had a mixture of electric guitar strings and requires further study once a culture of tuning for the sympathetic strings starts to take more concrete shape.

3.8 Tuning

The halldorophone has no default tuning. When users first get their hands on it, they tend to tune the main strings to standard cello (C_2 G_2 D_3 A_3), but often do custom tunings after having spent time investigating the instrument. Recently, a consensus is forming around the following tuning for the primary strings:

C1 (32.7Hz), **G1** (49Hz), **D2** (73.42Hz), **A2** (110Hz).

This tuning originates from Johan Svensson's 2012 piece, *Composition for Viola and halldorophone*; he and the cellist investigated various tunings until they arrived at one that got them the feedback behaviour they liked:

"we decided that tuning the instrument down one third (from cello tuning) gave the best result. But as I remember it, it was not easy to decide the tuning; some sounds and pitches came more easily with one tuning and some other with another tuning." [Svensson, personal communication]

Other users have since found this tuning to make for lively feedback behaviour contrasting with the standard cello tuning, which is often too tense to set the strings feedbacking. The lower, sympathetic string set has no culturally implied tuning and tends to be tuned in complement to strings in the upper set (unison, octave up or down, etc.).

4. USER FEEDBACK

The first cello-like iteration of the instrument was extensively workshopped with various collaborator who´s initial feedback confirmed they found the instrument exiting to perform with and gave critical reflection on control features and ergonomics. For example: Volume control for strings was changed from rotational potentiometers to sliders (affording visual feedback of volume level). Clearance for bowing was increased by accentuating the angle of the fingerboard and elevating the bridge. An individual-string, whammy system operated by the left hand as seen in Figure 8 was abandoned in the following versions as most performers did not use it.

Figure 8. Left-hand operated whammy.

In the intervening years some collaborators (non-cellists) have found the whammy levers on the first instrument it to be intuitive and interesting, consequently it will be brought back in future version for further exploration.

Halldorophone features have been evaluated through informally structured user research cycles, where musicians either have had the instrument on loan for their own music or through collaborations instigated by the author. The features comprising the instrument today are amalgamations of the reflections collected in these sessions over the years and design improvements have mostly been attempts at shaping the instrument in line with what the users see as desirable.

Notable music projects using the halldorophone and giving critical feedback so far, include: Múm, Max Lilja, Markus Hohti, various members of the S.L.Á.T.U.R collective, Hildur Guðnadóttir, including her collaborations as halldorophonist for: SunnO))), The Knife, Jóhann Jóhannson[2] and others. The halldorophone has been used in Guðnadóttir and Jóhannson's recent successful projects, including their instrumentation in acclaimed film scores, such as Arrival, Sicario, and Eiðurinn. By now the halldorophone is in constant use and has become part of the musical vocabulary of some of its long-term users who continue to give report on its use[3].

4.1 Halldorophoneness

There has been one notable exception to the user-directed design philosophy generally applied; the author's intuition has been at odds with some of the users on the theme of *control*. The question has been posed whether to include combinations of parametric equalization, band-stop, band-pass filtering of the individual string signals in the integrated interface of the halldorophone to allow for more stable, note-accurate feedback. This has been a topic of much debate, ultimately it was luthier Hans Jóhannson who suggested that perhaps fine-grained control is not what makes this instrument interesting, but rather its unwieldiness. This has since been confirmed by users, as demonstrated, for example by a sentiment expressed by Hildur Guðnadóttir:

"It's really unpredictable, very much alive. Every sense has to be tuned up. I'll be working a feedback but if I move my shoulder, it kills it. I have to be 100% present. Performing alone can be boring, but there's a different energy when my bandmate—the instrument—has its own ideas." [8]

Guðnadóttir and other users (generally the composer-performers) embrace and celebrate this "right" amount of unpredictability afforded by the instrument. At composition workshops, such as the one organized at the 2016 ICLI conference, where composers and performer collaborated in making pieces for halldorophone and Andrew McPherson's Magnetic Resonator Piano [13], users generally start articulating a sense of shared "authorship" with the instrument once they start to make music with it.

4.2 Writing music for halldorophones

A symposium was organized at the Iceland Academy of the Arts in 2015 called *Notating for the halldorophone* brought together a panel of composers who had recently worked with the instrument. The event was enlightening on the topic of control and reproducibility.

Hafdís Bjarnadóttir has composed a piece for the halldorophone where the instrument was set up in such a way that control of the feedback was routed to a mixer she operated during performance. This setup seems to have addressed the issue of controlling the feedback to her liking and she notated other parts of the music conventionally, with informal notes to herself on volume. Bjarnadóttir added that:

"This is a rare and good opportunity for composers to meddle with what's going on stage because usually you sit in the audience helpless and hope they don't screw up. But here you can actually do something to spice it up, so I thought that was really fun." [20]

The implication being that Bjarnadóttir resolved the chaos-perceived-as-indeterminacy issue by incorporating an improvisatory aspect to the composition, fulfilled by herself.

Guðmundur Steinn Gunnarsson presented his method of animated notation for the halldorophone and discussed his approach:

"The instrument, really, at some points gets to play itself. And I think most of the things I had figured out [...] they were reproducible but in order to make them work there had to be enough time in the score." [20]

In other words, Gunnarsson accepts the aleatoric, fluid behaviour of the halldorophone and tailors his approach. His animated notation seemed well suited to the task of "giving space" for feedback events to manifest while allowing the player to mentally prepare forward in time for the next event.

The seminar reinforced the understanding that the somewhat uncooperative quality of the halldorophone is its most prominent characteristic and central to its identity.

5. FUTURE WORK

Two new halldorophones, *The Sisters,* are set for completion in 2018. They are identical, except one has analogue electronics and the other will use a Bela board [12] for pre-amplification and mixing which affords easy embedding of filtering functions for more accurate feedback manipulation and control. Now that the identity of the halldorophone is somewhat stabilized (embracing the complexity of the feedback as its dominant characteristic), it is of interest to facilitate use where a greater level of control can be asserted over the feedback and to subsequently evaluate user approaches with this new affordance.

The timbral quality of a halldorophone drone is sometimes reminiscent of the sound of Indian classical music, especially when feedbacking strings strike the fingerboard (or are intentionally touched gently by the player) creating a buzzing sound. The buzz can be similar in quality as that of sounds made on the tanpura and other instruments having a buzzing bridge or "Jivari" (in the Indian classical tradition) this is a "lipped" bridge, having an area close to the terminus of the string where the vibrating string will graze up against it creating a overtone rich buzz. Developing such a lipped bridge for halldorophone is of interest and will be implemented in coming years as an experimental feature.

Alternative methods of detecting string vibrations are of interest. Although the currently used Nu pickup by CycFi is a huge improvement on the previously used pickups hand fabricated by the author, electromagnetic pickups do have a recognizable character and it is appealing to experiment with a very clean (linear in response) method of detection such as in the custom optical pickup in the Overtone Violin [15].

In an ongoing collaboration with Alice Eldridge and Chris Kiefer who were inspired by the halldorophone in building their "feedback cellos" [7] we intend to document and disseminate an

[2] Who´s untimely passing has happend between the writing and publishing of this paper. I met him last this past summer in good form in his studio in Berlin, where I remember him fondly.

[3] Projects involving halldorophones are informally archived by the author at: www.halldorophone.info

open hardware kit for feedbacking classical strings. This will include designs for physical parts (such as clamp-on, adjustable bracket for pickups to fingerboard) and a list of commercially available electronics.

One aim of the kit project is to attempt positive results with a non-invasive method (as opposed to physically embedding speaker cones in the back of the instrument as with the feedback cellos), a success along these lines is of interest as it is likely to accelerate the development of a performance practice for string feedback (as it requires less commitment on behalf of users).

A version of this method has recently been implemented on double bass by colleague Thanos Polymeneas-Liontiris [16].

6. DISCUSSION

The method of instrument development described here can be viewed as anachronistic compared with most contemporary NIME research (which tends to be focused on digital platforms and new hardware technologies as they become available). The work being done with the halldorophone is closer to that of traditional acoustic lutherie of previous centuries where features are refined on a decade or century-scale in long, committed interaction between instrument maker, instrumentalists and composers. This slower tempo has certain advantages in terms of feature refinement and culture-building for the instrument but is also at risk of staying committed to technologies and methods superseded by better tools (such as evaluation strategies employed in HCI and interface design).

7. CONCLUSIONS

The Halldorophone project is a study in creating a new musical instrument with a bespoke identity, gains acceptance by practicing musicians. The project has been successful and the main qualities leading to this success are: clear visual and conceptual identity around distinct, uncommon affordances (string feedback) wrapped in a familiar package (cello-ish) where users can recycle pre-existing playing techniques. The fine-grained control of the instrument's feedback (through a clear interface for individual string gain control) combined with an unpredictability which can be brought to a state of complexity verging on chaos, make halldorophones unique feedback-based instruments.

The method of development hails to pre-industrial traditions of lutherie and makes the case that a slower pace of development can be beneficial in culture-building for a new musical instrument. Current ongoing research involves exploring this slow pace of development through engagement with users, equally: composers, performers, audience, luthiers and musicologists.

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