

Reinventing the Noisebox: Designing Embedded Instruments for Active Musicians

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ABSTRACT

This paper reports on the user-driven redesign of an embedded digital musical instrument that has yielded a trio of new instruments, informed by early user feedback and co-design workshops organized with active musicians. Collectively, they share a stand-alone design, digitally fabricated enclosures, and a common sensor acquisition and sound synthesis architecture, yet each is unique in its playing technique and sonic output. We focus on the technical design of the instruments and provide examples of key design specifications that were derived from user input, while reflecting on the challenges to, and opportunities for, creating instruments that support active practices of performing musicians.

Author Keywords

embedded acoustic instruments, digital fabrication, participatory design

CCS Concepts

•Applied computing → Sound and music computing; Performing arts; •Human-centered computing → Participatory design;

1. INTRODUCTION

The NIME design community, well known for the prolific creation and investigation of new digital musical instruments (DMIs) and interfaces, is complemented by a community of creative practitioners who actively use and explore new technologies in performance. In fact many wear both hats, actively participating in the design of new instruments as an integral part of their compositional and creative practices.

However, researchers have found that most new DMIs experience limited real-world use in musical performance or production, if any at all. A variety of reasons for this have

been offered. It may be an intentional choice by designers, who may develop instruments as research probes not meant for musical practice [12]. With DMIs that would be put into musical service, issues of build quality and reliability are frequently cited as limiting factors for their adoption into sustained real-world use [14]. Furthermore, lacking established instrumental techniques, adequate forms of musical notation, and canonical repertoires [7], new instruments face steep challenges towards their widespread adoption [9], highlighting the importance of shared communities of practice for their success [8, 16].

1.1 Towards Design for Performance

In a previous work, we had conducted an online survey to poll musicians about their use of new instruments and technologies [15]. We found several elements of the respondents' performance practice that influenced the instruments and technologies respondents were willing to work with. For one, the survey indicated that more frequent performers are less likely to use non-commercial DMIs in their practice and are more reliant on software and off-the-shelf controllers than those who perform less frequently in public. Additionally, while [12] previously found that performers from the NIME community are usually closely involved with designing and building the DMIs they use, we found that this is much less common outside of NIME-based practices (including those not involved with academic research and who perform in more popular music styles).

Based on these findings we were interested to develop instruments that can support the demands of active and professional performance through the involvement of expert musicians from diverse performance communities during the design process. The result was the development of three new DMIs that are based on an existing platform for standalone instruments called the Noiseboxes [13], with design features that came from early user feedback and a set of co-design workshops.

There were three main reasons for redesigning an existing instrument instead of starting from scratch. First, the basic standalone design establishes some useful constraints in terms of size, interaction capabilities, and fabrication materials and methods, ensuring that new designs are manageable in scope and can be reliably produced with available resources. Second, our previous development cycles offer a reliable and tested base to build off of, while still remaining open and flexible to support new creative designs. Lastly,



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the Noisebox was originally designed as a research probe for previous projects and was never used in authentic public performance, which now presents an opportunity to rethink the design process towards these ends.

2. THE NOISEBOXES

The original Noiseboxes were conceived out of practice-based research and development of *embedded acoustic instruments*, defined by [2] as “an embedded musical instrument that provides direct sound output”. Each carries out its own computation onboard with a Raspberry Pi or similar single-board computer and produces sound via onboard amplification and mounted loudspeakers, while integrated sensors provide user control of sound synthesis parameters.

The instruments are fully standalone with the inclusion of an internal rechargeable battery. One of our original aims with the Noisebox design was to imbue a digital instrument with some inherent qualities of conventional acoustic instruments that may be missed on a DMI. For one, onboard sound production and battery power make for immediate playability with no need for connections, configurations or additional hardware to get started. For another, a standalone instrument combines input device and sound production into one cohesive unit, reversing a defining attribute of DMIs (the decoupling of control from sound production [11]).

2.1 Technical Design

Two distinct versions of the Noisebox were developed, yielding multiple copies of each.

The first version (top and right of Fig. 1) utilized the Satellite CCRMA framework for embedded instruments [3], comprised of a Raspberry Pi for sound synthesis, onboard mapping and general system functions, an Arduino Nano microcontroller for sensor acquisition, and a custom Linux (Raspbian) distribution. Mapping and audio programming was done in the Pure Data visual programming language.

Sonically, the instrument functions as a “drone box”. It is comprised of a polyphonic FM synthesizer with embedded sensors mounted on the laser cut enclosure to control the number of voices and their frequencies. An internally mounted inertial measurement unit (IMU) modulates various timbral parameters with the instrument’s movement and orientation. An enhanced model was also produced that included delay and reverb effects and sound presets that could be interpolated.

A second version (bottom and left of Fig. 1) of the instruments was constructed the following year. The instruments functioned similarly to the v1 instruments, and also included a base model and an enhanced model equipped with additional effects. However the underlying architecture was redesigned to use an early version of the *Prynth* framework for embedded instruments¹ [5]. Similar to Satellite CCRMA, *Prynth* uses a Raspberry Pi as the processing base, but utilizes purpose-designed PCBs with an integrated Teensy 3.2 microcontroller for sensor acquisition, and uses the SuperCollider programming language for onboard audio processing and mapping. An appealing feature of *Prynth* is that it runs a web server that can be accessed through any network-connected browser, which hosts a SuperCollider code editor and provides convenient access to management and configuration options.

3. USER FEEDBACK AND WORKSHOPS

For the second version of Noiseboxes we ran a small pilot study that explored how performers appropriate new

¹<https://prynth.github.io/>



Figure 1: The Noiseboxes, v1 & v2 (Clockwise from top left): v1 initial prototype, v1 finished, v1 with additional controls and audio FX, v2 with additional controls and FX, a quartet of v2 instruments.

instruments and develop personalized playing styles. Following the basic format of a previous study by [18], four participants were given an instrument to take home for one month. After two weeks they returned individually to report on their progress and give a short demonstration performance with the instruments. At the end of the month they returned as a group to give another performance, this time with a small invited audience in attendance. Feedback was collected from the participants and audience members through interviews, questionnaires and a round table discussions.

While much of the feedback — and study — concerned the participants’ engagement and development with the instrument, some key issues with the instrument design were identified that would disqualify it for real-world use. Overall sound quality was lacking, mostly because of the inexpensive small onboard speakers but also due to component failure in one of the instruments. Participants and audience members alike recommended more interesting sound synthesis, greater variety of sounds, and better user controls for sound parameters. Performers reported noticeable latency between user input and sound, which made the instrument feel unresponsive and difficult to control. Finally, while the “retro” aesthetic of the instrument was appreciated, the sharp corners of the laser cut acrylic enclosure and location/placement of controls made the instrument uncomfortable and difficult to play.

3.1 Co-Design Workshops

In addition to the feedback from the pilot study, we solicited design input through a set of co-design workshops with expert musicians that were run in a parallel project. Inspired by the “magic machine workshops” described in [1], we engaged participants in open exploration of interface design through nonfunctional prototyping.

Ten performers who maintain an active public performance practice participated, divided in two sessions. Dur-

Table 1: Emergent workshop themes that were implemented into instrument designs

Theme	Keybox	Stringbox	Tapbox
1. Flexible performance modes	synth, looping & effects modules; external audio input	note-based & sequencer performance modes	dual synthesis modes
2. Extending existing instruments	piano-style keyboard & classic subtractive synth format	guitar-style strings & grid-based control surface	cajon-style input device
3. Embodied interaction and playful engagement	ergonomic rounded corners & recessed touch keyboard	asymmetrical shape & physical strings	entire instrument is controller

ing the workshop they crafted nonfunctional DMI prototypes from primitive crafting materials (posterboard, paper, sticks, glue, etc.) based on an initial creative design prompt. Presentations and discussion followed, yielding novel ideas for interaction and high-level suggestions for the design of new instruments they would be willing to use in their own performance practice.

While the workshops are part of ongoing research that will be documented in a separate report, we show examples of three emergent themes that led to specific design implementations (shown in Table 1):

1. Supporting flexible performance modes with multi-function controls, audio and control signal routing and modular functionality.
2. Extending or taking inspiration from existing instruments by incorporating conventional elements into new designs.
3. Encouraging tangible, embodied interactions and playful engagement with textures, shapes and materials that possess unique physical and tactile properties.

4. REINVENTING THE NOISEBOX

With our current project, we wanted to reinvent the Noisebox to address some of the issues with the originals and create new unique, highly playable, stable instruments that would be appealing to performers and robust enough to withstand the rigors of real-world performance. The result is three new instruments that combines feedback and lessons learned from the original designs with new ideas from the workshops, while employing a refined set of digital design and fabrication tools (Figure 2).

4.1 Instrument 1: The Keybox

Our first instrument in this series is a radical departure from the largely inharmonic noise-based timbres of the past versions. The Keybox (Fig. 3) is a two-oscillator polyphonic subtractive synth featuring a Moog-style filter, amplitude envelope, effects section, and looper with external

audio input. It is equipped with an onboard OLED display, four multifunction rotary encoders, 8 buttons and a 20-note piano-style capacitive touch keyboard. Whereas the previous Noiseboxes were best at producing dense swarming chaotic drones, the Keybox is immediately easy to play, control and understand, while the multifunction encoders, buttons and display provide access to a host of parameters for deep modulation and sound design.



Figure 3: The Keybox.

The Keybox utilizes the same computing hardware as its predecessor, utilizing a Raspberry Pi 3 Model B+ for audio processing and general system function, and a Teensy 3.2 microcontroller for sensor acquisition. However the software framework has been redesigned from the ground up. Sensor data is encoded into bytes on the Teensy using the *Consistent Overhead Byte Stuffing* (COBS) protocol. This facilitates the efficient and reliable transfer of data with minimal latency [4], which has shown substantial improvement over previous versions. On the Raspberry Pi, all audio



Figure 2: CAD renderings of three new Noiseboxes (L-R): the Keybox, Stringbox, and Tapbox.

synthesis and control mapping is done in the SuperCollider language, which receives the incoming sensor data from the Teensy via hardware serial port.

The onboard display functions separately from the rest of the instrument processing. When parameters change, new data is sent as OSC (Open Sound Control) messages from SuperCollider to a Python script which updates the display. The display can move between several pages of grouped parameters with the two red buttons to its left. Each page displays eight parameters, mapped to the four rotary encoders and four buttons to the right.

The fabrication of the Keybox and the other new instruments are revised as well. The enclosures are constructed from a combination of 3D printed frame assemblies and laser cut panels. While the instruments are mostly true to their “box” names, our updated fabrication materials and methods permit rounded, smooth edges for a more ergonomic feel, and allow for the possibility of alternate shapes, angles and more freeform designs.

While the Keybox is finished and playable at present, we continue to make incremental enhancements. In its current form it lacks direct sound output, but an updated version of the enclosure will include onboard amplification, which is a feature of the other instruments. Additionally, we have installed an IMU that will map movement of the instrument to user-selectable sound parameters.



Figure 4: The Stringbox.

4.2 Instrument 2: The Stringbox

The Stringbox (Fig. 4) is a digital synthesizer inspired by the form and function of a ukelele. The primary function of the instrument is a physically modeled string synthesizer that can be played in traditional guitar (or ukelele) fashion. Four strings provide an excitation source through plucking or picking (or alternately by bowing, rubbing, scraping, etc.) A 4x8 matrix of soft elastomer buttons sit on the short neck of the instrument that can be pressed as fingerings on a fretboard to determine the pitch of the corresponding string’s note. A simple implementation of the Karplus-Strong synthesis algorithm provides a string-like sound, and the instrument can be played as one would play a ukulele.

Alternately, a separate mode can fully reconfigure the instrument, and while the physical and visual similarities may remain, it becomes totally different. In this mode, the 4x8 grid can function as a sequencer, with different pages to determine sound sources and synthesis algorithms, sequences and arpeggios, while the strings can be manipulated by the user to modulate the corresponding audio track.

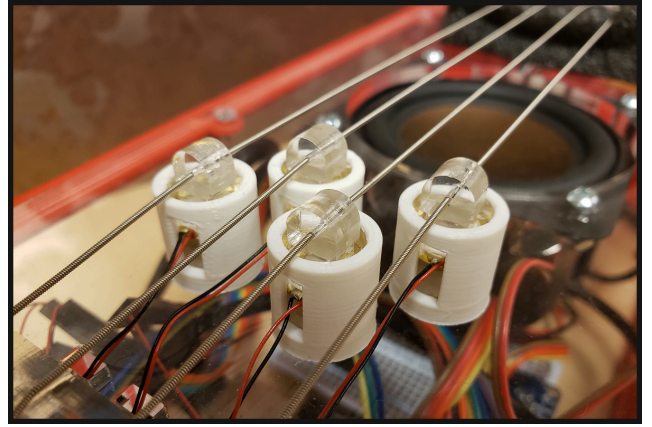


Figure 5: Detail of the Stringbox piezoelectric pickup assemblies.

The core hardware of the Stringbox is the same as the Keybox. A Teensy 3.2 receives sensor data, encodes it with the COBS protocol and sends it to SuperCollider running on a Raspberry Pi for audio synthesis and processing. Simple string pickups (Fig. 5) are made from small piezoelectric elements sandwiched between rigid discs of laser cut acrylic and mounted in a flexible 3D-printed housing. The pickup design is based on the approach developed by [6], where string excitation is carried to the coupled piezo, which outputs a corresponding voltage that is passed to an analog input of the Teensy. Two types of data are extracted from the piezo input: an event trigger with corresponding velocity (as with the initial pluck of a string), and a continuous data stream resulting from the vibration of a plucked string or sustained excitation (as in the case of a bowed string or other string interaction).

An onboard speaker gives the player an option for direct sound output, while audio can also be routed through a parallel audio output jack. An embedded IMU allows for further modulation of sound parameters through the movement of the instrument. While the hardware is finalized, additional features are planned for the instrument including additional synthesis models and deeper functionality of the sequencer module.

4.3 Instrument 3: The Tapbox

The third and final instrument in the series is a digital percussion instrument (Fig. 6). Each face of the rectangular instrument consists of a discrete panel that “floats” on rubber washers attaching it to the instrument frame. Five of the faces are equipped with large piezoelectric elements held flush to the inside of each panel, each mapped to a different voice of the embedded synthesizer. The instrument can be played by drumming, tapping, knocking and rubbing the various surfaces of the instrument and exciting the different synth voices. The final face is equipped with two small speakers, USB ports for charging and reprogramming purposes, and a volume/multipurpose slider.

An IMU is embedded within the instrument which, in addition to modulating synthesis parameters based on movement, serves a particular function. There are two synthesis modes mapped to the instrument which can be selected and mixed based on the absolute orientation of the instrument.

In its normal upright state, signals from the piezoelectric elements are each routed to a physical model of an N -segmented tube. This produces a unique bell-like tone for each interaction. Rotation and movement of the instrument changes the parameters of the virtual tube segments,

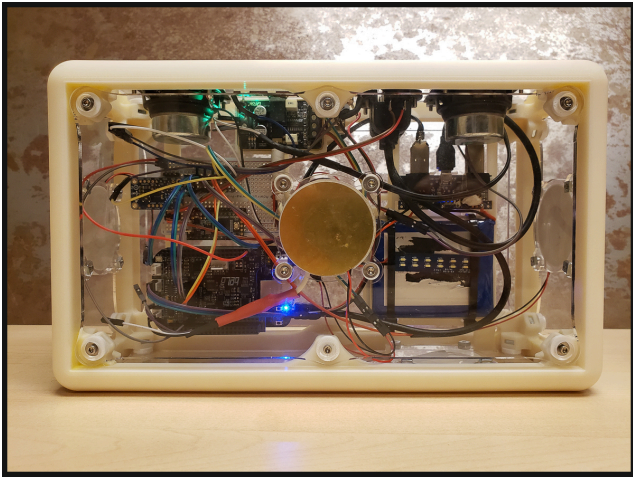


Figure 6: Top view of the Tapbox.

modulating the frequency, duration and timbre of the tones.

When the instrument is rotated into an upside-down orientation, the controls are mapped to a synthesized drum set, with each face a trigger for a different drum or cymbal. As with the first mode, movement and rotation can modulate the drum sounds in different interesting ways. Additionally, with the instrument held near the midpoint between the two, the modes are cross-faded proportional to the angle of orientation.

The synthesis method for the first mode processes audio directly from the piezoelectric element, whereas the second uses a layer of feature extraction to trigger sample playback when an onset (strike or slap, etc.) is detected. These two methods are extreme ends of a continuum, and any combination of feature extraction and audio signal can be mapped to synthesis parameters.

The technical design and hardware of the Tapbox is a slight departure from the architecture of the Keybox and Stringbox, as it is built on the *Bela*² platform which runs on a BeagleBone Black single board computer. Percussion tasks demand considerably lower latency than other more legato instrumental gestures. Selected for its exceptionally low latency and readily accessible audio rate signal acquisition [10], the Bela proved to be the ideal platform to bring this instrument to fruition.

As with the other instruments, we continue to explore ways to improve the Tapbox. We are experimenting with various preparations of the panels, applying several materials to bring a diversity of textures into instrument play. Rippled hot glue, felt, tree bark and glued pebbles can decorate the sides of the instrument that provide the performer with an array of surfaces to hold, rub, or strike. On the flat felt, hand slapping is effective; on the pebbles rubbing like a güiro is a possible playing technique.

5. CONCLUSIONS AND FUTURE WORK

From the original Noiseboxes, we hope these instruments are improved in several ways. First, we have addressed a number of design and performance issues that our pilot study identified. High quality loudspeakers and overall improved hardware design provide better sound quality, while the instruments employ a range of synthesis and effects processing methods, making for more interesting and diverse sounds. Improved software design and the use of a highly efficient data encoding algorithm have decreased latency to

²<https://bela.io/>

within acceptable bounds for adequate control intimacy [17] on the Keybox and Stringbox, while for the percussive gestures of the Tapbox we have opted to use the ultra-low latency Bela platform. And with the use of CAD design and fabrication tools, we have crafted more ergonomic and playable interfaces.

Along with these improvements, ideas generated from workshops with expert musicians have resulted in unique design choices that will make the instrument interesting and engaging to use.

This project is still ongoing, and an important future step will be to organize a longitudinal user study with the instruments that will allow us to evaluate if and how the informed design choices support the instruments' use in performance and to assess prolonged engagement over extended periods of time. Furthermore, the instruments' software continues to be updated with new features and refinements to the existing sounds and controls.

6. CLOSING REMARKS

The three instruments presented here represent a dedicated focus on the development of new digital musical instruments that will be both appealing and robust for long-term, engaged use in real-world performance practice. We believe that our user-driven approach may ultimately lead to greater uptake and longer term use that many DMIs currently experience.

Our work here is only one part of the equation towards bringing DMIs into more active performance practices. For one, there is a distinction to be made between commercially available instruments which benefit from industrial-production technologies and non-commercial DMIs designed and constructed using readily available maker tools and technologies. Furthermore, it is vital to acknowledge the important role that community-building plays in the development of performance practices around new instruments.

However, with this and related work, we hope to promote design processes involving performers to best meet their needs in terms of DMI use and performance within and beyond NIME, with new tools and new techniques to support ever-evolving musical practices.

7. ACKNOWLEDGMENTS

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8. ETHICAL STANDARDS

The user research described in Section 3.1 has been approved by the McGill University Research Ethics Board, File #188-0918.

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