Hybrid Hand Drum: Where Tradition Resonates Through Technology

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ABSTRACT

This paper presents a hybrid frame drum that entangles acoustic and digital elements, merging the expressive depth of traditional percussion with the expanded possibilities of digital sound processing. Designed with 4 key principles - portability, hybridity, simplicity and low latency - the instrument allows for a fluid interplay between physical and real-time digital augmentation.

Equipped with piezoelectric sensors, an FSR, and a DSP algorithm the drum extends its sonic landscape while preserving its acoustic presence. The design maintains an organic relationship between physical interaction and digital processing, and the three potentiometers provide intuitive yet flexible control, maintaining a balance between minimalism and expressivity. The bela platform ensures very low latency (7.55 ± 0.13 ms), making it highly responsive for live performance.

User evaluation highlights its potential for expressive control and seamless hybrid performance while suggesting ergonomic and functional refinements. Future enhancements, such as feedback control and DSP presets, could deepen the entanglement between performer, instrument, and sound. This research explores the intersection of acoustic and digital sound, contributing to the design of hybrid instruments that blur the boundaries between physical resonance and electronic transformation, expanding possibilities for musical interaction.

Author Keywords

NIME, proceedings, Augmented drums, Digital musical instruments, Electronic percussion, Music technology, New interfaces for musical expression, Sound & music computing, Active acoustics, Hybrid instruments

CCS Concepts

•**Applied computing** → **Sound and music computing;** *Arts and humanities;*

1 Introduction

1.1 Motivation and Background

In the ever-expanding world of electronic drums, where systems become increasingly complex and expressivity is pursued through various approaches, there exists a subtle need for simplicity[6] and a longing for the acoustic sound. A drum that combines both the organic acoustic output with electronic enhancement in its sound has a certain appeal.

This preference for *organic* sound can be seen as part of a broader desire for *authenticity* in musical experience. In contrast to the sometimes sterile or mechanical qualities of digitally produced sound, organic sounds carry microvariations, imperfections, and resonances with them, that are characteristics of the physical world.

Most commercial electronic drum systems use sample-based sound generation, where striking the drum head triggers a sample based on the hit's velocity. While this allows for consistent reproduction and a degree of expressivity, it often lacks the dynamic depth and sonic detail of real acoustic instruments. To address this, some developers have added positional sensing, creating zones on the drum head to trigger different samples or modulate effects. This enhances expressivity by responding to where the drum is struck, offering a more nuanced and closer approximation to the behavior of an acoustic drum. Other systems capture the actual audio from the drum using sensors, and processing this signal through real-time digital signal processing (DSP). This approach creates a hybrid drum, blending acoustic and electronic elements into a single expressive instrument. Unlike sample based approaches, this keeps the real-time variability and complexity of the original acoustic signal, allowing the drum to maintain its organic qualities even as it is transformed or manipulated electronically.

This hybrid approach speaks to a broader aesthetic and experiential value. The hybrid drum becomes a balance between control and unpredictability, tradition and innovation, the human and the machine. The expressive potential is not only in the sound produced but in the responsiveness and feel of the instrument.

However, despite these advantages, only few commercial products embrace and employ this sort of hybrid approach. Notable examples include the aFrame by ATV[1] and Sensory Percussion[2], which will be discussed in the following sections.

1.2 Objectives of the Study

This study aims to explore the potential of a hybrid drum, one that combines acoustic sound captured by sensors with real-time electronic processing. Unlike traditional sample-based electronic drums, this drum uses real-time audio, preserving the organic nature of the sound. By doing so, it aims to bridge the gap between the raw, tactile expressiveness of acoustic instruments and the expansive sonic possibilities of digital synthesis, making it a richer, more nuanced experience of musical interaction.

[1] `http://www.aframe.jp/`
[2] `https://sunhou.se/`

NIME'25, June 24-27, 2025, The Australian National University, Canberra, Ngunnawal and Ngambri Country, Australia.

1.3 Scope and Applications

The Hybrid Hand Drum in this study is designed for portability, modeled after a traditional hand drum. It operates independently of all cables except for audio connections in live performances. This design prioritizes usability in both studio and live settings, enabling expressive, real-time sound manipulation to enhance performances.

2 Related Work

2.1 Hybrid Instruments in percussion

A noticeable amount of Hybrid drum approaches are surfacing on the commercial market, with various interesting approaches. Below is a selection of both commercial and academic projects, with a brief description of the technology used.

ATV's aFrame — using a mesh batter head, combined with piezoelectric sensors, FSR (Force Sensing Resistor) and an advanced DSP to create a hybrid drum with lots of expressivity. The aFrame is based on real-time audio processing, taking the audio-signals directly from the piezoelectric sensors.

Digitally Active Drum (DAD) [14] — an enhanced snare drum, with in-built speaker, a sound transducer, near field photoelectric sensors, and a sound synthesis and effects patch, built to get the best of both worlds – acoustic capabilities and the versatility of digital sound processing.

Hybrid Percussion [1] — a PhD thesis exploring the extension of physical instruments using sampled acoustics. Particularly relevant to this study is the exploration of the Frame Drum, which served as inspiration for the development of the Hybrid Hand Drum.

Mandala V3[3] — a multi-layered drum with multiple hit zones, which combines piezoelectric sensors with capacitive sensors. This design makes the Mandala V3 drum very versatile, able to trigger different samples depending on the zone you hit. It is velocity sensitive and can be played with both hands and drumsticks.

Korg Wavedrum[4] — similar to the Mandala V3, but with two striking zones: the head and the rim. It detects hits with a combination of piezoelectric and pressure sensors, making it velocity sensitive. The drum incorporates advanced synthesis and sampling capabilities, resulting in a versatile sounding instrument.

Sunhouse Sensory Percussion — this technology stands out by using sensors attached to an existing drum set, processed through a Portal audio interface. The exact method is unclear, but it likely combines magnetic field sensing, piezoelectric sensors, and/or photoelectric sensors. A pickup element attached to the drum head acts as a reflective surface or magnetic field. The system detects hit locations (up to 10 zones per drum) and velocity, enabling various samples and nuanced tonal responses.

2.2 Sensor Technology in Music

Most of previous mentioned projects (2.1) are using piezoelectric sensors and force sensing resistors (FSRs), which are particularly relevant to this project and briefly described here.

Piezoelectric sensors, typically of a ceramic material or crystal, generate an electric charge when put under mechanical stress, such as deformation, which can be pressure, impact, vibration or bending[12]. In stringed instruments, they act as pickups converting vibrations into an electrical signal. In percussive instruments, they usually serve as triggers in electronic drums and integrated in hybrid drum setups (e.g. *aFrame* and *Hybrid Percussion*[1]), capturing vibrations and impacts for a more natural feel. Piezoelectric sensors are effective at detecting timing and sound, a single sensor cannot determine position, though this can be achieved by using four sensors in a square layout [10] [13].

FSRs change resistance based on applied force or pressure, with low resistance under pressure and high resistance when no force is applied. The core consists of a conductive layer and a resistive film[12].

Commercial products like TrapKat XL[5] use FSRs to detect the force of strikes and controlling parameters, similar to *aFrame*, *Hybrid Percussion* and *Korg Wavedrum*.

[3] `https://www.mandaladrum.com/`

[4] `https://www.korg.com/us/products/drums/wavedrum_global_edition/`

3 Design and System Architecture

3.1 Initial design requirements

The research in this paper focuses on a hand drum, a drum that doesn't require anything else than hands, and is very portable. Using the hands for drumming gives the opportunity to a, practically speaking, more hands-on experience, and hence both a direct interaction between the player and the drum, and more expressive drumming. The particular hand drum in this research, is a tunable drum, which gives the possibility to change the frequency of which the drum vibrates, and therefore affects the sound.

One requirement for this instrument is the possibility of playing without the need to be connected to any computer or other hardware. Since keeping the drum head, the sound produced is a combination of the synthesized sound from the DSP and acoustic sound from the drum itself. Due to the requirement of portability, the drum needs to be designed so that everything can be within the structure of the drum, and the only connection in the final product would be the audio output. In short, the requirements are following:

- High portability
- Hybrid - Both acoustic and synthesized sound
- Simplicity - easy to play and change the output characteristics
- Low latency

4 Implementation

4.1 The Build

A laser-cut wooden insert was designed to integrate the electronics into the drum (drum measuring 10", 25.4 cm in diameter), serving multiple purposes:

- A mounting platform for all components
- Secures the FSR to the drum head using a foam block
- Allows easy attachment for the bela board and potentiometers

The piezoelectric sensors are attached directly to the skin of the drumhead using double sided tape. The bela board is attached externally on the wooden insert for easy access. Figure 5, illustrates the placement of components and build in a cut-through view. The wooden insert is held in place by a combination of a tight fit and the drums tuning screws/pegs. The prototype build is shown in Figure 1.

[5] `https://alternatemode.com/`

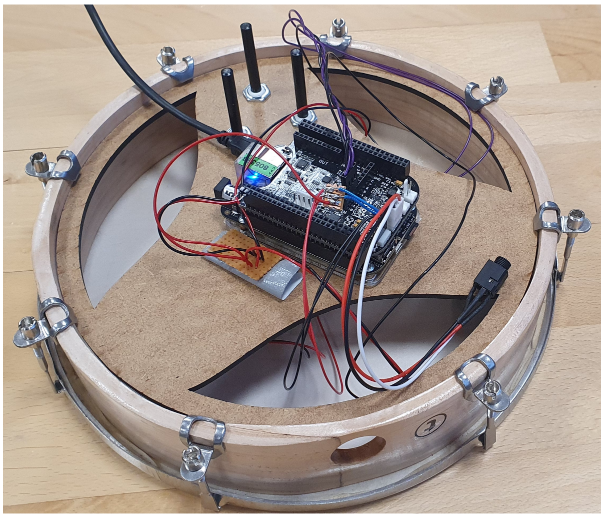

Figure 1: The drum built, with everything mounted on the insert

4.2 Hardware

The hardware design prioritizes low-latency signal processing and high-quality audio. The bela cape and BeagleBone black was chosen for their ultra-low latency, multiple audio-rate I/O, and real-time audio processing capabilities. A block diagram is provided in Figure 2. The setup has the following sensors and control:
- **Two piezoelectric sensors** to capture variations on strike position - center or edge.
- **A FSR** at the edge to sense pressure on the drum head.
- **3 potentiometers** to control parameters.

The FSR is secured by using foam blocks between the drum head and insert at the drum's edge, to preserve acoustic qualities.

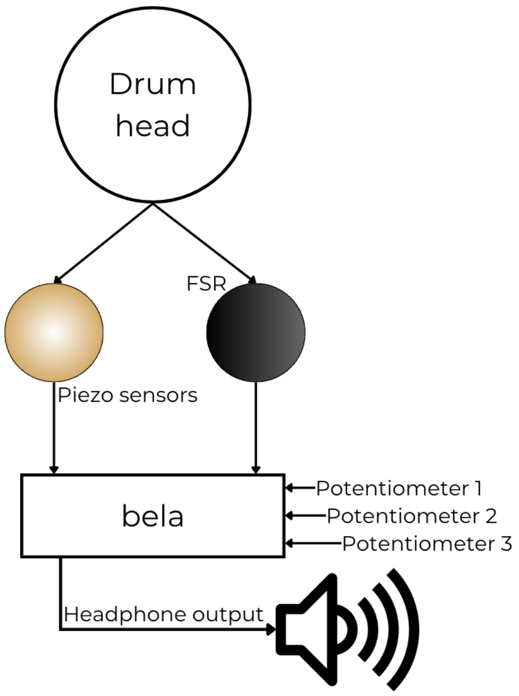

Figure 2: Schematic of Hybrid Hand Drum system

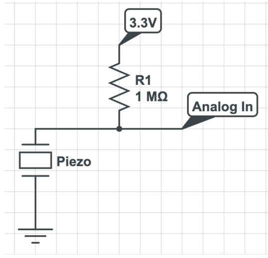

Figure 3: Piezosensor circuits

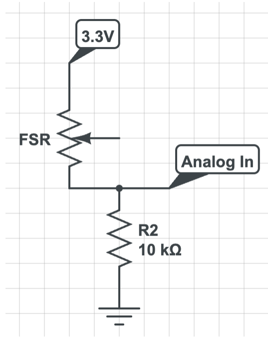

Figure 4: FSR circuit

4.2.1 *Sensor Circuitry*

The sensor circuitry and connection to the bela board was taken from the bela tutorial suggestions. The two pins of FSR is connected to 3.3V, and analog input 6 (adc∼ 6) with a pull-down resistor of $10k\ \Omega$, ensuring a pull towards logical low, and preventing floats.(Figure 3 According to the voltage divider formula (equation 1, where R_1 = FSR, R_2 = 10k), when pressing the FSR causes the resistance of the sensor to decrease, and the voltage goes up. (Figure 4)

$$V_{\text{out}} = V_{\text{in}} \cdot \frac{R_2}{R_1 + R_2} \tag{1}$$

The potentiometers are simply connected with the middle pin to their respective analog input, [adc∼ 3], [adc∼ 4] og [adc∼ 5].

The piezoelectric sensors are connected to 3.3V via a pull-up resistor of $1M\ \Omega$, creating a high-impedance load and preserving stability in the signal, but also increasing the sensitivity of the sensor. The sensor are connected to the audio input left and right on the bela pinout, corresponding to [adc∼ 1] and [adc∼ 2] in Pure Data. (Figure 3)

4.3 Software

4.3.1 *DSP Environment*

The software is programmed with Pure Data[6] (Pd-vanilla) due to its intuitive visual block-interface based programming language, focused on audio[11]. Two modules were designed for the Hybrid Hand Drum, the Karplus-Strong synthesis and a reverb. Flow diagram of the signal processing is in Figure 6.

4.3.2 *Karplus-Strong*

The sound synthesis algorithm chosen is the Karplus-Strong, which essentially is a method of simulating the sound of plucked string instrument using digital signal processing[5]. The process start with a burst of sound, e.g. burst of noise, mimicking a plucked string. The sound is passed through a delay line, where the length of the delay determines the pitch of the string. This signal is passed through a low-pass filter to the output with the present signal. The feedback decays and reverberate over time, and thereby simulating the damping effect of a plucked string. The Karplus-Strong is chosen for the Hybrid Hand Drum study for the very interesting sound it creates when playing the drum, with the continuous vibration of the drum head. It is aligned with the idea intended for the synthesis, an abstract, heavy and filling sound that contributed to the acoustic sound of a drum.

[6] `https://puredata.info/`

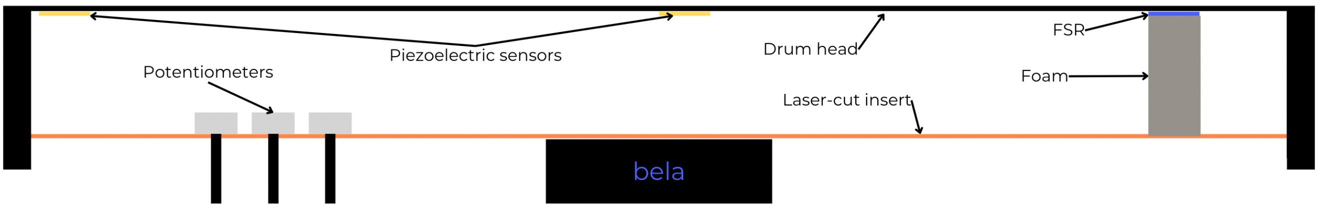

Figure 5: The build of the drum viewed as a cut-through from the side.

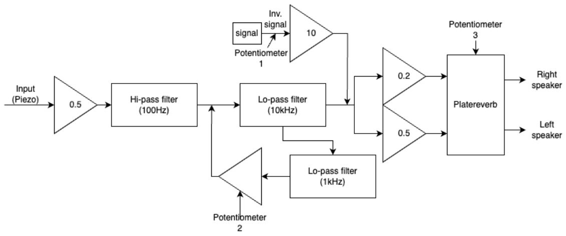

Figure 6: Flow diagram for the signal processing

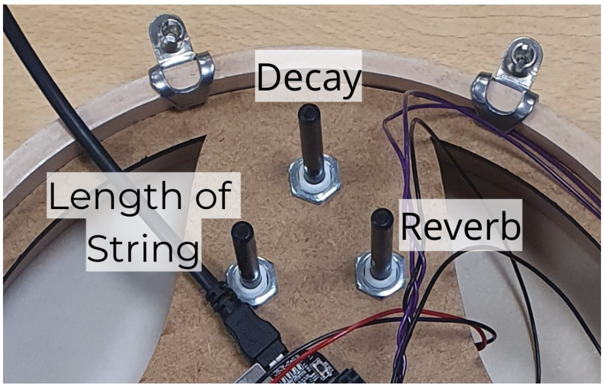

Figure 7: Mapping of potentiometers

4.3.3 Reverb

For adding a supporting effect to the Karplus-Strong synthesis, a pre-build plate-reverb from a bela tutorial project (Pitch Tracking)[7] is implemented. As the implementation of the reverb was not in focus, the different pre-build reverbs in Pure Data was tested, and it was concluded that the platereverb supported best the sound picture of the Hybrid Hand Drum. This plate-reverb is a digitized version of the acoustic-mechanical plate-reverb, metallic plates that are used in recording studios to make artificial reverb in recordings[2].

4.4 Mapping

The three potentiometers control pitch, decay and reverb, as these parameters have the biggest impact on altering the sounds characteristics. Mapping was intended to be natural and simple, according to how a hand drum is usually being played. The two natural spots for hitting the drum is in the center and the edge, which explains the placement of the sensors. The placement of potentiometers was designed to have easy access, and ease of implementation in scope of this project. The two piezo sensors are mapped to two different Karplus-Strong algorithm, differing only in the "length of string" parameter for the piezo positioned closer to the edge. Strikes near the edge naturally produce a higher-pitched sound with a shorter decay, while strikes at the center result in a lower-pitched sound with a longer sustain. The two piezos, center and edge, are panned slightly to the left and right, respectively. This design is aimed to create a deeper, bass-heavy tone when the drum is struck at its center.

A demonstration of the Hybrid Hand Drum can be found at the YouTube link in the footnotes[8].

5 Iterations

5.1 Iteration 1: Sensors & bela

The very first step was to write a program, connect the piezosensors and get audio through the bela. When this was obtained, the synthesized sound was developed and implemented.

5.2 Iteration 2: Testing on handdrum

Second step was to test how the piezosensors picked up the raw audio from the handdrum. A small pcb with a couple of potentiometers and connections was developed, and testing some parameter controls as well.

5.3 Iteration 3: Putting it all together

The last step to get the prototype, was putting it all together. This step included laser-cutting an insert for everything to be mounted on, finalizing the pure data code with the Karplus-Strong, and limit and decide parameter control to 3 potentiometers.

6 Evaluation

The development and initial evaluation includes autobiographical design (ABD) from the first author who is the creator and designer of the instrument. Research shows that the ABD approach is often used by human-computer interaction developers when designing new systems[9, 7].

Sound Quality - The sound is rough at times, with frequent clipping making control challenging depending on parameter settings. The clipping may occur due to the very high voltage produced by the piezoelectric sensor, and requires a more complex or sophisticated circuit, to be able to handle the high, sudden voltage spikes. Despite clipping, the drum is very responsive and requires time to master.

Latency - To measure latency, a microphone (Shure SM57) was placed just 5-10 cm away from the head of the drum. The output signal of the bela and signal from the microphone was connected to separate input of an audio interface (Focusrite Scarlett 2i4, 2$^{\text{nd}}$ generation). The drum was then struck repeatedly, both on the edge and centrally, with and without the effects turned up, while recording directly into

[7] `https://learn.bela.io/tutorials/pure-data/audio/pitch-tracking/`
[8] https://youtu.be/xwmcN8q1Y5w

Sonic Visualiser [9]. The time interval between each onset was measured at both with no effects, and with string decay. The average was taken as the average. Latency measured to be 7.55 ± 0.13 ms, within the 10 ms acceptable Digital Music Instrument(DMI) threshold[3].

Playability, Durability and Reliability - As a prototype, its durability is limited due to loose components and wires. At times, the sound becomes uncontrollable due to either the loudspeaker-drumhead feedback (see 7.1) or excessive decay parameter settings.

6.1 Test session with Musician

A less formal, semi-structured test session was set up with an experienced drummer(32 years, 16 years of experience, former professional), whose preferred genre to play is metal, jazz and electronic music. The test participant is also experienced in playing the bodhrán[10], a traditional Irish frame drum, which is why the test session was approach with similar techniques. Though, firstly, the participant explored the drum playing with the hands, and shortly after moved to primarily using a stick, as one would do with a bodhrán.

6.1.1 Notes and Suggestions

The participant found the drum intuitive and responsive, but suggesting ergonomic improvements, such as sensor placement, parameter labeling, and a larger 14" size drum, to better fit the playing style. The FSR was well-placed, aligning naturally with the placement of hands. Though it was suggested to use the FSR to control the reverb effect. Initially the participant enjoyed the reverb extensively but later explored other parameters. A few dead-zones were observed during the testing, suggesting a careful placement of sensors. Other suggestions for improvements are assigning sound trigger to the rim, different sound triggers across zones, enhance response to brushing, ergonomic adjustments (placement of bela, potentiometers height and placement, and labeling parameter control) or even a direct control of parameters while playing.

6.1.2 In Summary

The test confirmed the drum's expressiveness, which could further be improved by direct parameter control. Overall it was an intuitive and fun instrument to play. A summary of suggested improvements follows:
Sensor Placement: Address dead-zones by optimizing sensor positions.
FSR Use: Map to reverb control for dynamic expression.
Sound Triggers: Assign triggers to the rim and enable different sound zones across the drum.
Brushing Sensitivity: Improve response to subtle techniques.
Ergonomics: Adjust placement of the Bela board and height of potentiometers; label parameter controls clearly.
Parameter Control: Implement real-time control during play.
Drum Size: Increase drum size from 10" to 14" to better match the bodhrán playing style.

7 Discussion

The Hybrid Hand Drum is an example on how musical interfaces are not just tools for performance, but integrated components in a dynamic relationship between performer, technology, and environment. Rather than separating digital synthesis from physical gesture, this instrument invites an embodied and entangled mode of interaction. One where acoustic resonance and electronic manipulation co-exist in real-time. By combining tactile percussive play with direct control over sonic parameters, it encourages spontaneous exploration and amplifies the performer's expressive freedom within a responsive sound environment.

This entanglement also extends to cultural and contextual layers. Drawing inspiration form traditional frame drums, the instrument maintains a familiarity in form and playing technique while facilitating new, digitally enhanced expressions. The simplicity and portability of the design reflect an intention toward accessibility and practical use in diverse performance settings, while also making space for iteration and co-development with users.

7.1 Advantages and Limitations

The Hybrid Hand Drum offers flexible real-time audio processing, allowing adjustment of parameters during performance. The real-time sound manipulation, can encourage more playfulness and creativity while playing. Unlike pure electronic drums, the Hybrid Hand Drum keeps the acoustic qualities, making it possible for both acoustic and electronic performance. On the other hand, the Hybrid Hand Drum has several limitations. An immediate limitation is the feedback between the drum head and speakers, as airborne vibrations gets amplified through the piezo sensor. To minimize this issue, the drum needs to be perpendicular $\perp$ to the speaker. Latency, greatly minimized by using the bela platform, remains a consideration. The latency of 7.55 ± 0.13 ms, within acceptable performance threshold, could potentially impact very precise or fast performances.
The FSR placement reduces the acoustic output slightly, but with the position near the edge minimizes this effect. Furthermore, it was found that the implementation of the FSR did not have as big effect as intended, similar findings as A. Kapur *et. al.*[4]. Tuning relies on adjusting the parameter "length of string" with a potentiometer making precise note tuning a challenge. The drums reliance on a power source, whether if its through a cable or a battery, reduces the portability or flexibility in a performance. The same goes for the cable connection for audio, even though this is typical for electronic instruments.

The Hybrid Hand Drum offers an attractive combination of acoustic and electronic sound, giving a versatile platform for innovative percussionists. However, the practical limitations, such as feedback, fine-tuning the synthesized output and need for external power, emphasize the need for further improvement. Further iterations could tackle these challenges, to enhance the usability and attraction for musicians, and specially percussionists.

Comparing the hybrid hand drum in Table 1 to a selection of the before-mentioned drums in section 2, it shows that what sets the hybrid hand drum apart is the combination of portability, simplicity and lower cost.

7.2 Future Improvements

The Hybrid Hand Drum shows significant potential, yet improvements are needed to enhance performance, usability and overall functionality.

To reduce the airborne feedback, future versions could incorporate anti-feedback mechanisms or alternative drumhead materials, such as perforated metal, though it would either reduce or remove the acoustic output. Another great feature to implement would be the integration of more preset sound synthesis options to choose from, which would be a row of various emulations, but also other experimental sounds. Adding this and an LCD screen would improve usability by allowing quick parameter adjustment and preset selection. Integrating a battery would improve portability,

[9] `https://www.sonicvisualiser.org/`
[10] The history of the Bodhrán drum

Instrument	Key Features	Limitations
aFrame	Mesh head, advanced DSP, portable, low latency	High cost, no acoustic output
Sunhouse Sensory Percussion	Magnetic/photo sensors, zone-based control, expressive	Requires external drums
Hybrid Hand Drum	Low latency, portable, expressive, simplicity	Feedback issues, basic interface

Table 1: Comparison of Instruments

while better cable management and PCB design would improve durability. Refining the electrical circuits with filters or amplifiers could improve precision and audio clarity. Optimizing the response of the potentiometers could improve the parameter controls and the drums expressiveness.

After further play with the drum, it was revealed that the enhanced usability of the drum could be addressed by a redesign of the parameter interaction, for tweaking and playing with the parameters, such as decay and length of string while playing the drum, much like some hand drums are being played with dampening the sound from the back with the non-hitting hand. To catch further limitations not discovered by the first author, a proper evaluation process could be used, such as the System Usability Scale [8].

8 Conclusions

The goals of the Hybrid Hand Drum was to combine the tactile and expressive qualities of acoustic hand drums with the flexibility and functionality of an electronically enhanced drum. Low-latency, portability, simplicity and acoustic-digital performance was achieved, and gaining valuable insight from a user testing. The Hybrid Hand Drum show great potential, yet a list of future improvements has been identified to enhance is usability, versatility and performance. With the improvements suggested in 7.2, the drum can become even more powerful instrument for percussionists and experimental musicians, offering the best of both worlds of acoustic and electronics, while maintaining its expressive qualities.

9 Acknowledgments

The author would like to acknowledge the participant in this study, and assistance and support from fellow students and teachers of Aalborg University.

10 Ethical Statement

This project was developed with the aim of making hybrid instruments accessible to musicians of all backgrounds, regardless of gender or ethnicity. The Hybrid Hand Drum is designed to by portable and intuitive, making it low entry for percussionists. No data was collected from individuals outside the creators of the project, and the musician who participated in the evaluation gave informed consent, with the option to withdraw at any time. Feedback was anonymized to ensure privacy.

While the author strove for an inclusive and versatile instrument, some limitations remain. Those with limited or no hand mobility may find it challenging to play and use the drum. Additionally, musicians with visual impairments may face difficulties adjusting parameters without additional accessible features. Future iterations will accommodate these challenges, and find was to improve usability for a broader range of performers.

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