bEADS
Extended Actuated Digital Shaker

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ABSTRACT

While there are a great variety of digital musical interfaces available to the working musician, few offer the level of immediate, nuanced and instinctive interaction that one finds in an acoustic shaker. bEADS is a prototype of a digital musical instrument that utilises the gestural vocabulary associated with shaken idiophones and expands on the techniques and sonic possibilities associated with them.

By using a bespoke physically informed synthesis engine, in conjunction with accelerometer and pressure sensor data, an actuated handheld instrument has been built that allows for quickly switching between widely differing percussive sound textures. The prototype has been evaluated by three experts with different levels of involvement in professional music making.

Author Keywords

Digital Shaker, Nime, DMI, Actuated Instrument, PhISEM

ACM Classification

• **Applied computing~Sound and music computing**

1. INTRODUCTION

Electronic percussion has been commercially available since the 1980s. Their use, and the sounds they can produce have become more sophisticated and they are used in many genres of music.

Sales of electronic drum-kits have been steadily increasing for year, and now appear to be outselling their acoustic counterparts. [11] The Electronic Percussion Industry Council (EPIC) has recently been established to help promote and educate in the use of electronic percussion. [2] These instruments are clearly popular and are likely to continue increasing in popularity.

In many music circles a distinction is made between the title of *Drummer* and *Percussionist.* Whilst drummers are indeed percussionists, there are percussionists who have great success without sitting behind a drum kit. Other electronic percussion formats are produced, such as the MalletKat, but electronic percussion seems to have evolved mostly from the drum-kit and the drum-pad. [14] What of percussionists who are not drummers? Would they not benefit from an interface that caters to their highly refined set of gestures, that can cover a myriad of sounds and control possibilities?

Commercial electronic percussion products have become increasingly sophisticated since they first became popular in the eighties. But the reasons for the continuing increase in their uptake amongst musician's remain the same. Ben Meyer reviewed these advantages which are summarised in table 1. [13]. A review of drumming forums revealed some common criticisms, whilst these criticisms may not be universally applicable or accurate, they give some indication as to consumer perception, and therefore *Digital Musical Instrument* (DMI) design requirements.

In music technology circles there are interfaces that present a variety of possibilities for capturing gesture for musical purposes. They are not in any way restricted to the drum-kit paradigm and many of them, such as Navid Navab's *Gesture Bending* and Greg Beller's *Synekine Project*, have been applied with percussive effect. Performers such as Alex Nowitz, Andrew Stewart have also achieved expressive and sophisticated musical performances using non-conventional music controllers (Wii remote and T-stick), but these examples seem to be the exception rather than the rule [23, 25].

The physical form and method of interaction with an instrument using physical modelling was investigated with Physmism [8]. One of the findings was that a well designed and natural feeling interface can easily be appreciated by a musician when exploring the possibilities that physical modelling can provide.

[15, 16, 24, 7] Despite the great artistic potential of these technologies, the commercial trends seem to be pointing even more towards the portable rather than the expressive. *DrumPants*, *Aerdodrums* and *Freedrum* all do away with the need for a drum surface to provide a small physical footprint and quick set-up, and seemingly sacrifice some degree of nuance in the process. [3, 1, 4]

Numerous studies have investigated the impact of cutaneous transfer of audio information in various Human Computer Interaction (HCI) scenarios. O'Modhrain and Essl developed *Pebble Box and Crumble Bag* to *"uncover instances of coupling, however loose, between the haptic and auditory senses"* [19]. In *Playing by Feel* O'Modhrain lays out a model of motor skill acquisition in the practice of a musical instrument where the methods a musician employs to monitor the state of their instrument and their own performance progress through various stages, she argues that haptic feedback can play an important role in learning a new instrument [17]. Cook also considers haptic feedback as a potentially valuable tool in a digital musical instrument. He employs a solenoid in his *Haptic Maraca* to open up this feedback modality within the format of a shaker [10].

Amongst the most valued qualities of acoustic instru-

NIME'17, May 15-19, 2017, Aalborg University Copenhagen, Denmark.

Table 1: Pros and cons of Electronic Percussion

Pros	Contras
Low Acoustic Volume	Not as responsive to velocity as acoustic alternatives
Portability	Aesthetic preference for acoustic sound
Small physical footprint	Dictates sound for recording
Ease of recording	Not as responsive to playing subtleties
Versatility	Feels very different to acoustic kit
–Triggering Possibilities	Requires amplification, even for practice
–Midi output	Technical difficulties in performance
–Combination with *Virtual Studio Technology* (VST)	High repair costs
–Use of sampling to afford being able to change drum sounds	

ments is ability to transfer the more detailed aspects of music, beyond timing and overall dynamics. These details are clearly important to the musician, but also have an impact on the audience. Many electronic percussion instruments cannot distinguish between the strike of a drumstick and the tap of a finger. Clearly this is a shortcoming, one only has to consider the care that drummers take in choosing the weight, material, design and general style of their sticks. The ability to completely change sound, and make noises that would not normally be possible with an acoustic instrument are the cherished advantages of a digital approach.

Shakers are a sub–group of percussion instruments that can be found in a wide variety of shapes, sizes and materials. They can be found in various forms in most cultures and date back to at least three thousand years ago. [20] Most musicians are familiar with their use at some level, and for most humans, a shaker, in the form of a rattle, is the first music instrument they are likely to hold. Interaction with these instruments is both instinctive, and sufficiently intricate to allow for expressive use. This paper describes a prototype DMI – bEADS (see figure 1) which has been designed in the hope that such an instrument open up the world of Electronic Percussion to a new group of musicians. Unlike Cook's *Haptic Maraca*, bEADS is modelled after a generic form of shaker where the performer's hand is in continuous contact with the primary resonant material of the instrument. This model was chosen as it is more typical of the shakers that are in common use across music genres, allows for the exploration of standard playing techniques related to grip variation (implemented as pressure sensor readings) and mimics shakers where a more significant level of cutaneous information transfer might occur.

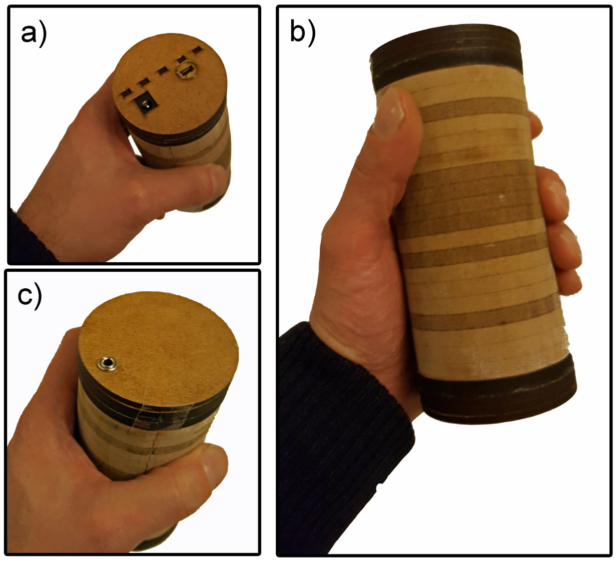

Figure 1: bEADS

2. AN ACTUATED DIGITAL SHAKER

bEADS stands for Extended Actuated Digital Shaker. It takes advantage of the gesture vocabulary associated with an acoustic shaker, extends the possible interaction and sonic capabilities of shaken idiophones and is actuated to provide a realistic, credible user experience.

2.1 Construction

The shaker housing was made from laser-cut 6mm MDF. It housed all of the following equipment with the exception of the laptop running the Max/MSP patch.

A Grove - IMU 10DOF motion sensor was used as an accelerometer. Gyroscope information was not used in an attempt to reduce latency in the Arduino code. A single 5 mm Force Sensing Resistor (FSR) was sandwiched inside the shaker housing. An Arduino Uno was employed to send IMU and FSR data to Max/MSP which generated both audio and haptic output. These signals were sent to the three watt class D stereo acoustic amplifier board powering the two 1 watt audio exciters, which were attached to the inside of the shaker housing.

2.2 The Synthesis Engine

Taking inspiration from PhISEM, as described in [9], a synthesis engine has been created to mimic some of the qualities of shaker instruments.

The accelerometer data is used to create an amplitude envelope, this envelope is applied to a white noise signal. A threshold is then created by multiplying the envelope by a user defined factor. When the enveloped noise exceeds the threshold a *collision* is modelled with an impulse signal output. The envelope is then applied to the series of impulse signals.

This stochastic signal is then sent to a bandpass filter. Instead of attempting to simulate existing materials, control of the filter parameters is carried out by manipulation of the shaker, thus extending the expressive capabilities of the instrument.

2.2.1 Colouration

During the initial stages of software development a simple sonification approach was used to explore the possibilities of bEADS. Assigning the frequency of elementary wave forms to direction of force led to entertaining results. This led to the metallic and Cuica modes described below.

2.2.2 Mapping

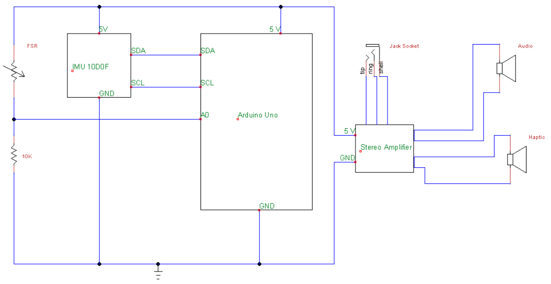

Figure 2: Schematic of bEADS circuitry

Sound synthesis is controlled via motion and pressure via the shaker, whilst various parameters and mappings can be defined via a Graphical User Interface (GUI) on the laptop running Max/MSP. See figure 3.

The accelerometer x, y and z data is converted from Cartesian to spherical coordinates so that magnitude and direction can be used for mapping. A constant approximating acceleration due to gravity is subtracted from the magnitude value.

2.2.3 *Envelope*

The magnitude of the spherical accelerometer data controls the amplitude of the synthesised sound, and by implication the envelope. Two line objects provide overlapping envelopes for attack and decay [1].

The attack and decay times, and their gain values can be altered via the GUI.

2.2.4 *Band Pass Filter*

The x value of the accelerometer is mapped to the centre frequency of a band-pass filter, this results in different filtering effects depending on the orientation and rotation of the shaker whilst in use.

Depending on user selection via the Max/MSP GUI, the width of this filter can be changed during performance by increasing or decreasing grip pressure.

2.2.5 *Metallic Sound*

When the metallic colouration is selected via the GUI, direction of force (azimuth and polar angles) control the frequencies of two dissonant sine waves.

The balance between metallic sound and collision sounds is controlled by the grip pressure.

2.2.6 *Cuica Sound*

When the Cuica colouration is selected the frequencies of two sawtooth waves are modulated by force direction (as with the metallic colouration) and by grip pressure. The tighter the grip, the higher the pitch.

2.2.7 *Haptic Feedback*

Haptic and audio signals are sent to separate transducers in the shaker housing.

Depending on the user selection via the GUI the haptic feedback can either follow the attack portion of the envelope, or the entire synthesised sound.

[1]It should be noted that in this scope *attack* and *decay* do not refer to standard ADSR parameters, but rather two line objects that govern the overall response to a given acceleration. *Attack*, in this instance might roughly equate to attack and decay, and *decay* representing sustain and release. In reality they overlap somewhat.

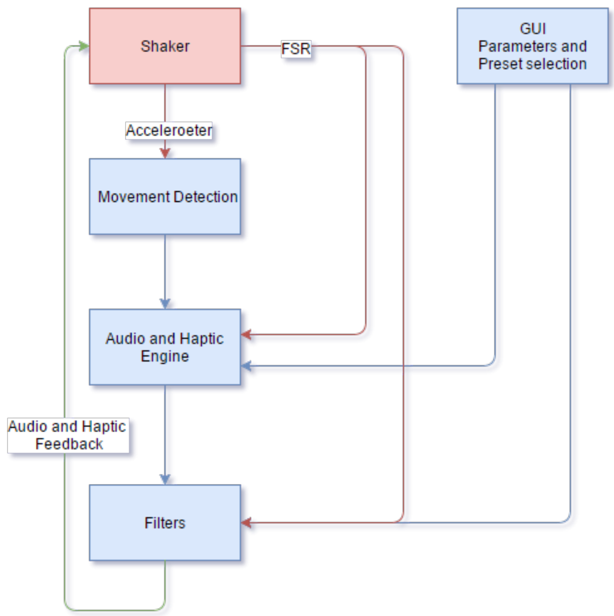

Figure 3: Coarse overview of the bEADS system

It was determined during development that when haptic feedback was governed by the entire acoustic amplitude the experienced became confusing. The preferred condition is obtained by using the attack portion of the signal.

Attempts to use the synthesised audio signal as the haptic feedback source were unsuccessful as often these signals did not result in the shaker housing resonating at a frequency that could be detected via cutaneous sensation.

A sawtooth wave at 40 Hz was chosen as the base vibration signal. This provides a high energy whilst still feeling natural. The selected envelope is then used to control the amplitude of this signal, which is subsequently filtered to ensure that any audible aspect of the haptic signal is reduced.

2.3 Evaluation

Three experts were selected to help evaluate bEADS. They were all male, aged between 38 and 53 and heavily involved in music in various ways. They all play percussion instruments. There were separate evaluation sessions for each expert. Evaluation took between three and four hours per person.

Evaluation took the form of a series of simple musical tasks, directed, informal interview, comparison to a selection of three acoustic shakers and open experimentation with the instrument. Video was recorded during evaluation and used further scrutinise interaction with the shaker.

2.3.1 *Playing with a Metronome*

This test was carried out first as it is a basic exercise and should therefore be possible if bEADS is to function properly. The feedback settings were also alternated to ascertain how effective the actuated design was. See table 2.

All three subjects were able to play along with a metronome, without instructions as to how to play. This test shows that the interaction is instinctive, and that bEADS is, at least at this elementary level, a functioning musical instrument.

There was no significant variation in Likert scores for playability between settings. However, all three expressed a strong aesthetic preference for having the acoustic and haptic feedback from the shaker. Each musician was asked to play in tempo with a metronome set at 120 bpm, for one

Figure 4: **Expert A testing bEADS**

Table 2: Feedback settings used for testing

Setting	Haptic	Audio Source
1	Yes	Shaker Housing
2	No	Shaker Housing
3	No	Laptop Speakers

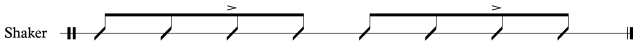

Figure 5: Rhythm pattern used for initial testing

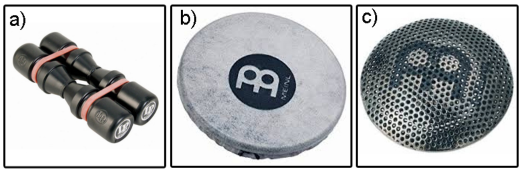

Figure 6: Three acoustic shakers used for comparison tests

minute, using a basic eighth note rhythm. See figure 5.

2.3.2 Informal Interview

Each musician was encouraged to play with bEADS, and the other three available shakers(see Figure 6) whilst discussing and evaluating a set of qualities and design aspects that had been chosen after reviewing various approaches to musical instrument evaluation. [18, 6, 22] These discussions continued throughout the rest of the testing session.

The overall response from the three musicians was positive. Feedback is summarised in table 3.

In addition to traditional shaker gestures and sounds, all three musicians found that new gestures could be used for a different set of musical effects. They felt it could be used as a sound effects controller. One expert stated that he felt it was an instrument in it's own right and could be composed for.

There was a consensus that the size of the shaker, combined with using grip pressure as a control gesture, led to fatigue in the hand.

The mapping of x value from raw accelerometer readings to filter centre frequency (see section 2.2.2) led to some confusion. It made the shaker very sensitive to rotation about the z axis, which was affected by how the user happened to be initially holding it.

2.3.3 System Usability Scale

An adapted *System Usability Scale* (SUS) questionnaire was used to determine how easily the control and GUI concepts were understood.

bEADS scored well – between 60 and 92.5. According to [5] this equates to an adjective rating between OK and Best imaginable.

Expert B scored the highest, significantly higher than either Expert C or Expert A. This fits with his observed playing – he appeared more confident than Expert A or Expert C, but less adventurous. Lower scores might be equated with an instrument that was more nuanced and complex, or a performer trying to decipher some subtle behaviour that they had detected.

2.3.4 Comparison to acoustic shakers

The experts were asked to play with each of the four shakers and line them up from best to worse for each of the qualities and design aspects discussed in section 2.3.2.

bEADS scored well in experienced freedom and possibilities, and explore-ability, on average beating all three of the other shakers. bEADS got it's worst rating for timing control and for learn-ability. Expert B and Expert A both stressed that they believed it was just a matter of getting to know the instrument. This result, combined with observations made in test 2, led to an experiment (see section 2.4) which uncovered latency and jitter issues which were

Experienced Freedom and possibilities	Expert A and expert B were excited by the possibilities, which they stated were beyond those of a normal shaker. Expert C felt that he needed more time to really judge this aspect. See Explore-ability
Perceived control and comfort	With the exception of Expert B, the experts found the size, unfamiliar response and use of grip pressure led to fatigue in their hands.
Perceived stability, sound quality and aesthetics	bEADS was judged to be stable and produced a professional quality sound. The volume produced was considered to be too quiet for anything other than solo practice.
Learn-ability	The control of filters, pitch and cross-fading between sounds, combined with behavioural differences from acoustic shakers, were considered to be something that required time to master. All felt that this could be accomplished with time. Expert A observed ”The more stories you can tell, the longer it takes to learn them”
Explore-ability	The musicians initially approached bEADS with a behavioural model built on prior knowledge of acoustic shakers. Expert C, being the least experienced musician amongst them found it more challenging to master rhythmic control of the new instrument. This became an obstacle to exploration. All three had different comments with regard to explore-ability, all were connected with learn-ability The professional musicians were most inclined to continue exploring.
Feature controllability	Overall the evaluators felt that, once they knew how to control the various features, that they were easy to control, or could be learnt. Expert C found controlling with orientation most challenging.
User experience	bEADS was found to be interesting, inspiring and enjoyable by all the experts. Expert B noted that holding the sound source in your hand made it feel like a real instrument. He considered haptic feedback to play an important role in this. All three found the wires somewhat frustrating. As noted above in perceived control and comfort, grip pressure led to hand fatigue.
Timing Controllability	Opinion was divided. Expert B found it no more or less difficult than other shakers. Expert A and expert C felt it was significantly different. Only expert C felt that it was significantly more difficult.
Categorisation	It was felt unanimously that bEADS could be described as instrument like, or as an extended instrument

Table 3: Key observations from experts

not immediately apparent during development.

2.4 Latency and Jitter

The bEADS shaker unit was placed on a thin cushion on a table. The audio output from bEADS and the in-built microphone signal were routed to separate channels of a Zoom R16 multitrack recorder. The bEADS shaker housing was then struck gently with an open palmed hand twenty times.

The resulting recordings were then mixed into a stereo file in Matlab. The difference in onset times between the microphone and bEADS output signals obtained using the measure tool in Sonic Visualiser was taken as Latency. Jitter was calculated from the differences between all possible pairwise combinations of the latency readings.

Latency and jitter were both found to be far higher than the recommended target values. See table 4.

In a study of latency tolerance for theremin performance it was noted that subjects over the age of thirty were less perceptive of latency. All the experts use in this study are over this age threshold. However, all subjects in this study were able to detect latency of around 100 ms with similar accuracy. In the same paper it is pointed out that a church organ can have several hundred milliseconds of latency, and can still be played with practice. [12]

The jit.fpsgui object is used in the bEADS patch to report frame update rate. This reports a value for frame update between 4.5 and 5 ms. This would result in jitter greater than the commonly used 1 ms benchmark, but not as high as the recorded values. Further investigation was carried out by recording the raw accelerometer data from within Max/MSP. These recordings showed that new values were being updated every 20 ms. The origin of this jitter is still the subject of investigation.

Average	Jitter			
Latency	**Max**	**Min**	**Average**	**SD**
115.3 ms	21 ms	0 ms	8.55	0.006

Table 4: Results of a simple latency test

These values require further study and explanation. In a parallel study an experiment has been designed to shed more light on why such high levels of jitter were not immediately apparent in development or evaluation. [21]

3. CONCLUSIONS

A prototype of an actuated digital music shaker instrument has been designed, built, and evaluated by three invited experts.

It is believed that such an instrument would provide musicians who do not play kit drums, particularly percussionists, with a tool to experiment with the freedoms and creative possibilities of digital musical instruments.

The current implementation can be improved upon by choosing higher performance components, reducing latency and Jitter, more closely modelling the behaviour of an acoustic shaker and allowing for integration with other systems via protocols such as Open Sound Control (OSC). Future iterations of bEADS could take advantage of technologies such as concatenative synthesis to extend the sonic palette of the instrument.

The high latency and jitter of bEADS is surprising given that the experts felt that the instrument behaved predictably with regard to timing. This could be an interesting area of further research, both to verify the results obtained during this study, and to understand this phenomena.

The author believes that the refinement of the existing mappings, GUI controls, and their integration into a single amplifier and control unit, combined with a more refined, perhaps wireless or entirely self contained shaker housing would result in an attractive addition to the world of electronic percussion. This belief is supported by the positive reaction of the selected experts who helped evaluate the instrument.

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APPENDIX

A.

- Arduino Uno
  - BUONO UNO R3
  - Clock speed 16MHz
  - Atmega328 TQFP-32 micro–controller
- TEAX13C02-8/RH Tectonic Audio Exciter
  - 8 Ohm nominal
  - 32.2mm x 26.3mm x 9mm
  - 10 grams
  - Voice coil diameter 133mm
  - Continuous power handling (weighted pink noise) 1W
  - Burst power handling (weighted pink noise) >2W
  - Operating temperature range -20 to 55° C (TBC)
  - Audio frequency range 500Hz to 20kHz
- FSR 400 Interlink Electronics
  - Actuation Force 0.2 N
  - Force Sensitivity Range 0.2 N – 20 N
  - Force Repeatability +/- 2%
  - Hysteresis 10%
  - Non–actuated resistance 10 Mohms
  - Rise time < 3 microseconds
- PAM8403 class-D audio amplifier
  - 3W Output at 10