DAD

- Digitally Active Drum -

Masters Thesis

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Abstract:

Despite the ever growing variety and popularity of commercially available electronic percussion instruments there are still a significant number of gigging musicians who prefer to use acoustic drums.
DAD is a digitally active drum that provides sonic capabilities associated with digital musical instruments in the form of an acoustic snare drum allowing full use of acoustic drumming gesture vocabulary.
By using an in-built loud speaker and audio exciter system, a Bela Cape and Beagle Bone Black, near field photoelectric sensors and a synthesis and effects patch built in pure data, a prototype of a an acoustic - electronic crossover instrument has been built.
This prototype has been evaluated by five drummers and two co-performers in both group and solo settings in order to determine it's effectiveness and it's potential role in professional music making.

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Preface

When I began my studies at Aalborg University I had a background which included twenty-five years experience as a professional musician. Naturally this had an affect on my choice of projects. Within eighteen months I had designed, either in groups or on my own, three musical instruments. They varied substantially in form and their academic goals. A digitally augmented replica of a medieval string instrument was adapted to make it easier for complete beginners to play. A novel tactile interface made of a wooden frame and heavy iron bars resulted in an alternative musical interface that would be intuitive for experienced musicians. A digital shaker gave the illusion, through audio and haptic synthesis, that it was an acoustic instrument. All of these were accepted for presentation at academic conferences.
Whilst learning of the communities surrounding the development of sound and music computing, as applied to musical expression, I was struck by the tendency for the designer of a new musical instrument to also be the intended performer. This contrasts strongly with the well established tradition in the music industry of the engineer, luthier or designer building a long standing relationship with the expert musician. Whilst the phenomena of *signature models* in music instruments is partly driven by the need to promote a product, it could also be considered a form of action research, where problems are not only solved, but but new ones identified, as the researcher stands alongside the subjects of a research project mutually sharing information and ideas [5].
It occurred to me that the building of these kind of relationships might reveal insights within the academic world of sound and music computing and its application in the development of new technologies for musical expression.
It was this train of thought that helped crystallise my interest in the themes chosen for this, my master's thesis.

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Chapter 1

Introduction

There have always been musicians who embrace the products of newly developed technology. Musical instruments are themselves the products of technical know-how. Even as far back as forty thousand years ago, and earlier, musical instruments were being developed. [15, 32]. As engineering and materials science progressed instruments became more complex and provided new dimensions for personal expression through sound.

The electric pick-up was patented in 1937, amongst the objectives listed were amplification, and removal of the need of a sound board or resonance box [35]. Inventions like this, and the public address system resulted in a new musical world where the excitation was remote from the sound production. The link between musicians action and sound creation became less direct. The sounds they could produce were previously unheard. This led to creative possibilities for performers and new experiences for some audiences, but some musicians and listeners were reluctant to take part. Bob Dylan's use of an electric guitar at Newport in 1965 was controversial enough for it to still be debated and talked about today [13]. There were many reasons for the controversy, but his audience, many of them musicians, were split in their opinion, and the migration from acoustic to electric guitar had played a role in this.

When the computer became a significant player in music production there was no longer a need for any physical dependency between the gesture and the produced sound. This resulted in virtually limitless possibilities for the instrument designer whilst further disassociating cause and effect in the view of the audience, and to a certain extent, the performer [29, 17, 6]. Again, some musicians and audiences were reluctant to follow. The combination of amplification and computer generated music provides a new world of expressive possibilities, but something is lost in the process. Computer generated sound has been adopted by many musicians, yet there are a significant number who are not interested, or inspired by it.

Some families of instruments have evolved with the integration of computing more successfully than others, at least in terms of commercially available products. The electric guitar is almost always used in conjunction with some kind of signal processing. This is often digital, though there are many guitarists who still prefer analogue equipment. Electronic percussion (EP) sells extremely well with products available at all imaginable price points [48]. It's clear that there are advantages and possibilities that computing can provide in the world of music performance, and yet many musicians still prefer acoustic instruments, avoiding digital processing wherever they can.

How can the possibilities available from electronic music be presented to those musicians who more interested in acoustic instruments?

1.1 The problem area

How to present the advantages and possibilities of digital instruments to musicians who are more experienced and involved with acoustic musical instruments.

This is a big area which needs to be reduced in order to define a problem that can be addressed within the time frame of this project.

There are a number of iconic music instruments which have integrated computing into their use. The author chooses to select an area from three of the most popular instrument categories.

- The guitar

  Electric, or acoustic, digital signal processing (DSP) is present in pedals, amplifiers and pre-amplifiers. Some musicians may not even be aware they are using digital sound.

- The keyboard

  This is an example where the digital solutions have been so well integrated that this instrument can be seen in almost any setting, from a solo performer playing dinner music to a large rock group. Some performers even use a digital piano housed within a fake piano body, giving the audience the impression of an acoustic instrument, whilst using an instrument that is easier to transport and does not need constant tuning.

- Electronic Percussion

> This category sells well. Total beginners and professional musicians alike often have a digital drum kit, but they are not seen as a replacement for an acoustic instrument in the same way as a keyboard is for a piano. They are also not seen at concerts as commonly as keyboards or even digital guitar effects pedals, this despite the advantages of portability and variety of sound characteristics that they exhibit.

It seems then, given this choice of popular instruments, the drum kit would be an area worth investigating. This also has the advantage of allowing the author to work with evaluators used in a previous study [50], thus exploring themes mentioned in the preface of this report.

1.2 Initial Problem Statement

> Design an artefact that presents some of the advantages of digital percussion to drummers who are predominantly interested in acoustic music instruments

Chapter 2

Background

2.1 Target Demographic

As implied by the initial problem statement section 1.2, the target demographic are professional and keen amateur players of acoustic drum-kits instruments.

A review of drumming forums conducted for a previous study revealed some common points of praise and criticism with regard to electronic percussion [51]. An updated version of these findings can be seen in Table 2.1. These are of relevance as they indicate some of the reasons that the target demographic might not already be using digital percussion.

2.2 Commercial Electronic Percussion

Electronic percussion has a longer history than one might guess. Synthetic and acoustic sound sources have been combined by sound designers since 1939 when John Cage composed imaginary landscape for two turntables playing test tones, a cymbal and a piano [23].

Drum machines and percussion synthesis also dates back to the nineteen-thirties [2].

The rhythm machine concept was popularised with the success of the **Wurlitzer Sideman** (1959). It utilised a combination of tape loops and filters to create drum like effects [46]. Introduced in 1973 the **Moog Drum Controller Model 1130** (see Figure 2.1) was likely the first commercially available form of electronic percussion. A piezo sensor and sensitivity controls built in to a plastic skinned drum acted as a trigger for a separate synthesiser [2]. There were no dynamic or timbre controls. This model of trigger and external sound synthesis continued until Pollard produced the **Syndrum** (Figure 2.1) which was also piezo trigger based, and had

Table 2.1: Pros and cons of Electronic Percussion

Pros	**Contras**

• Low Acoustic footprint
• Easily transportable
• Versatility
  – Trigger any sound
  – Midi Communication
  – *Virtual Studio Technology* (VST) Connection
  – Samples of other drum kits
  – More exotic sounds
  – Sound Effects
  – Built in signal processing
  – Wave table synthesis/Physical Modelling
• Compact
• No need for microphones
	• Velocity sensitivity issues
	• Aesthetic preference for acoustic sound
	• Aesthetic preference for acoustic appearance
	• Dictates sound for recording (Can't use a microphone)
	• Not as responsive to playing nuances
	• Feels very different to acoustic kit
	• Requires amplification, even for practice
	- Results in loss of collocation of sound
	- In the case of triggers, judging the mix of electronic to acoustic signals
	• Risk of technology failure
	• High repair costs

parameter controls built into it's frame, but was sensitive to attack velocity, and contained all the synthesis electronics within the same unit [46].

The eighties saw the introduction of the **Roland TR** series of drum machines. Their sound is still extremely popular today. The **Music Instrument Digital Interface** (MIDI) protocol was also developed, resulting in a rapid expansion of commercial products, and there was a rise in the popular use of electronic percussion [20]. There are now so many that some categorisation for different approaches is useful. Most commercially available electronic percussion products fit into one or more of the following groups:

- Electronic Drum-kit

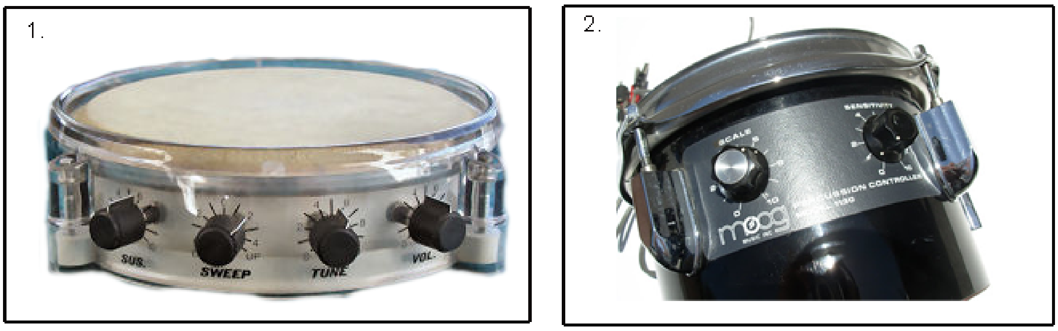

Figure 2.1: Early electronic percussion:
1. Syndrum
2. Moog Percussion Controller Model 1130.

These generally take the form of a set of pads arranged as an acoustic kit, which act as triggers connected to a separate sound synthesis unit.

- Electronic Hand Drums

  Designed to be played with the hands, usually self contained.

- Miscellaneous pads

  These are trigger pads based on other instrument formats such as the xylophone or tin drum.

- Trigger Pads

  As with Electronic Hand Drums, but focused on triggering high quality sound samples

- Triggers

  These can be attached directly to acoustic drums and used to trigger an output in response to the acoustic input. They are sometimes built into the drum, in which case they generally take the form of a cone touching the centre of the batter head. Mesh heads are drum skins made of a fine mesh wish allows air to move through the material, reducing the acoustic output of the drum. These are often used with triggers.

- Hybrid Systems

  The acoustic qualities of the instrument are preserved and make a significant impact on the output of the instrument.

Within the category of Electronic Hand Percussion two products stand out in that they allow different strike positions to change sound output. They use different technical approaches to achieve this:

The **Handsonic** (Figure 2.2) is comprised of a several small pad zones. Piezo sensors are positioned at the edge of the pad and force sensing resistors (FSR) are placed under the sensor pads. This, combined with a great number of controls built into the instrument housing, creates a complicated looking interface that does not resemble an acoustic instrument.

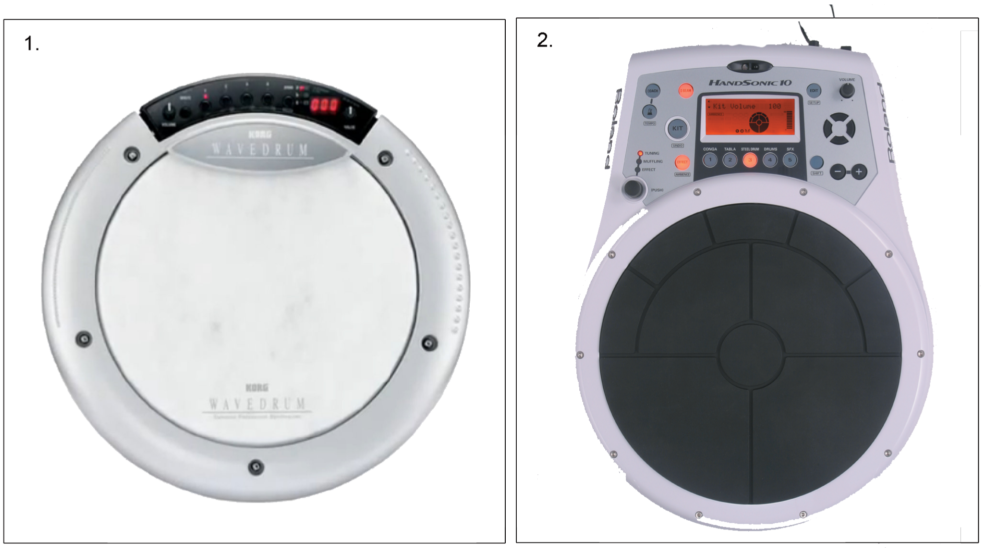

Figure 2.2: 1. Korg Wavedrum
2. Roland Handsonic HPD 10

The **Korg Wavedrum** (Figure 2.2) uses the acoustic sound of the drum head, detected through piezo pick-ups, to directly drive the synthesis. This allows the experienced percussionist a great deal of nuanced control. It has controls built into the housing of the instrument, but far fewer than the hand-sonic. This instrument is highly regarded but was not a commercial success. It has been suggested that it's capabilities were not understood by its target audience, and that this, combined with it's very high price point contributed to poor sales [2]. However, a revised version is now available, at a much lower price and no longer appearing so complicated within it's share of the market, it appears to be achieving better sales figures [48]. This instrument is designed to closely follow some of the core behaviour of an acoustic hand drum, but still requires headphones or an external amplifier to make any noise.

Another product that is able to variate response according to strike position falls within the electronic drum kit category:

V-Drums by Roland is a drum kit that is closely modelled, in function and appearance, on the acoustic instrument. They use the mesh head and conical trigger

method described above, indeed, this is where that design originated. Radial strike position is detected by analysis of the first half wave period of the signal collected from the sensor. Synthesis is achieved through a combination of wavetable synthesis and physical modelling.
Roland have captured something of the feel of an acoustic drum kit and combined it with some advantages of a digital approach. External amplification is required as no significant musical sound comes from the mesh heads. Many drummers combine v-drums with their acoustic kits, implying that whilst they appreciate the product, it does not provide the same experience as the traditional instrument.

There are aspects of some of these design paradigms which are relevant to the initial problem statement section 1.2.

- Electronic Drum-kits maintain the physical layout of their acoustic counterparts allowing for transfer of some of the drummer's basic gesture vocabulary.
- The Wavedrum looks more like an acoustic music instrument.
- Triggers have the advantage of being able to add to an traditional instrument without restricting acoustic response.
- Hybrid systems seem to have the potential to provide benefits of both acoustic and digital instruments. See section 2.4.

2.3 Innovations

Perc Pro by **Polyend** (See figure Figure 2.3) is a system of actuators that physically strike the individual instruments within a standard drum kit, allowing the drummer to share their kit with a drum machine. [39].
The drumming affected by the Perc Pro system is most likely predetermined, as such it is not under real-time control of the performer. The sound produced is entirely acoustic whereas the performance could be considered as under the control of a computer. One might reasonably assume that this lack of direct control may be unwelcome to the chosen demographic for this project.

Aerodrums uses a playstation 3 Eye camera as a sensor which tracks markers placed on drumsticks and the performers feet. This allows a very portable instrument as there is no drumkit at all. However, it offers none of the advantages of an acoustic instrument, and requires external amplification [1].

Freedrum is even more portable than Aerodrums. Sensors, most likey gyroscope and accelerometer, are attached to drumsticks and the performers feet. A smart phone app provides mapping and sound production [18].

Aerodrums and Freedrum both capture gesture directly rather than focus on the contact with a drum or cymbal. This gives them the advantage of portability, but removes something that lies at the very heart of acoustic musicianship; interaction with the instrument. Additionally, any system that relies on a sensor being attached to a drumstick, or part of the human body, prevents the possibility of spontaneously switching to a brush, beater, or even a single finger or elbow.

Drumpants does away with the need for any drumming equipment. Wireless sensors are worn, or placed on nearby surfaces. When struck theses sensors send information to a wide range of technologies including specially designed applications, as well as industry standard units [14].
This provides a great deal of versatility, but requires some music production knowledge that may not be possessed by this project's target demographic.

Boppad utilises a *Smart Sensor Fabric*. This technology allows both velocity and radial position sensing. It takes the form of a drum pad and provides the ability to assign different responses to different areas of the surface. This bears similarities to Wavedrum and Handsonic (section 2.3) [24].
This approach provides versatility and some degree of nuance, but in common with many other approaches it requires external amplification.

Figure 2.3: PercPro: a system of physical actuators that can be sequenced to play the drums

2.4 Hybrid Systems

2.4.1 Hybrid Percussion

DDrum Hybrid Drums Series
A high quality range of acoustic wooden shell drums with internally mounted triggers. The concept is very similar to Moog's Model 1130 (see Figure 2.1) but updated so that the audio output and the drum are both of much higher quality.

Zidjian Gen16
These cymbals are genuine acoustic percussion items, but have been crafted out of a perforated mesh to reduce their acoustic output. They are equipped with a pick-up system mounted under the cymbal, and a signal processing unit that filters the audio to change the tonal characteristics of the sound output.

In common with may EP products, DDrum and Gen16 seem to focus on modelling the acoustic characteristics of similar instruments. One cymbal or drum becomes which ever cymbal or drum the performer wants it to be, but it remains a cymbal or drum, both in terms of control interaction and sonic character. This retains some of the benefits of digital systems listed in Table 2.1 in terms of versatility of sound output whilst retaining much of the quality of interaction associated with an acoustic instrument. It does not seem to offer much in the way of new interaction possibilities or provide quite the range of sounds that electronic music is capable of. Neither does it deal with problems associated with amplification such as collocation, and related difficulties with balancing acoustic and digital sound levels.

EL Cajon
A recent innovation and hybrid percussion instrument, the El Cajon by Roland functions as a completely acoustic cajon, complete with internal snare wires. It also has two internal sensors, presumably piezo pick-ups that trigger a wide range of user selected, pre-loaded samples. The samples are played back through a front mounted speaker [16].
This is a very simple, yet apparently very effective method of creating a hybrid instrument. They have chosen to limit the user selection to samples rather than adding a variety of synthesis or sound effects making for a less complicated instrument.

2.4.2 Non-Percussion Hybrid Instruments

VO - 96

The VO-96 is a magnetic pick-up and actuator system combined with a capacitive touch user interface (UI). The UI is very discreetly placed on the scratch-plate helping the system merge with the acoustic guitar. It can work with any steel strung acoustic guitar [38]. The signal from the pick-up system is digitally processed to

Figure 2.4: VO-96 pick-up, actuator and synthesiser system

create a variety of synthesiser-like effects. The synthesised sound is then sent to the magnetic actuators, which manipulate the movement of the strings themselves. In a sense the strings are producing the synthesised sound.

This concept of using a part of the acoustic instrument, as what Navab, Nort and Wei might call a computational material [31], is very effective in this setting. It is highly likely to appeal to the musician who is fond of acoustic instruments as the instrument still reportedly feels like an acoustic instrument, and, thanks to the discreet design of the UI it places sounds that are the result of digital processing in there hands in an unobtrusive way.

Hybrid Pianos

Yamaha have a series of acoustic pianos that also house digital piano systems [21]. The digitally produced sound is optionally fed directly into the soundboard of the instrument using an audio exciter system.

Like the VO-96, the acoustic instrument is used as a natural convolution layer, the traditional feel and look of the instrument is entirely preserved and the audio

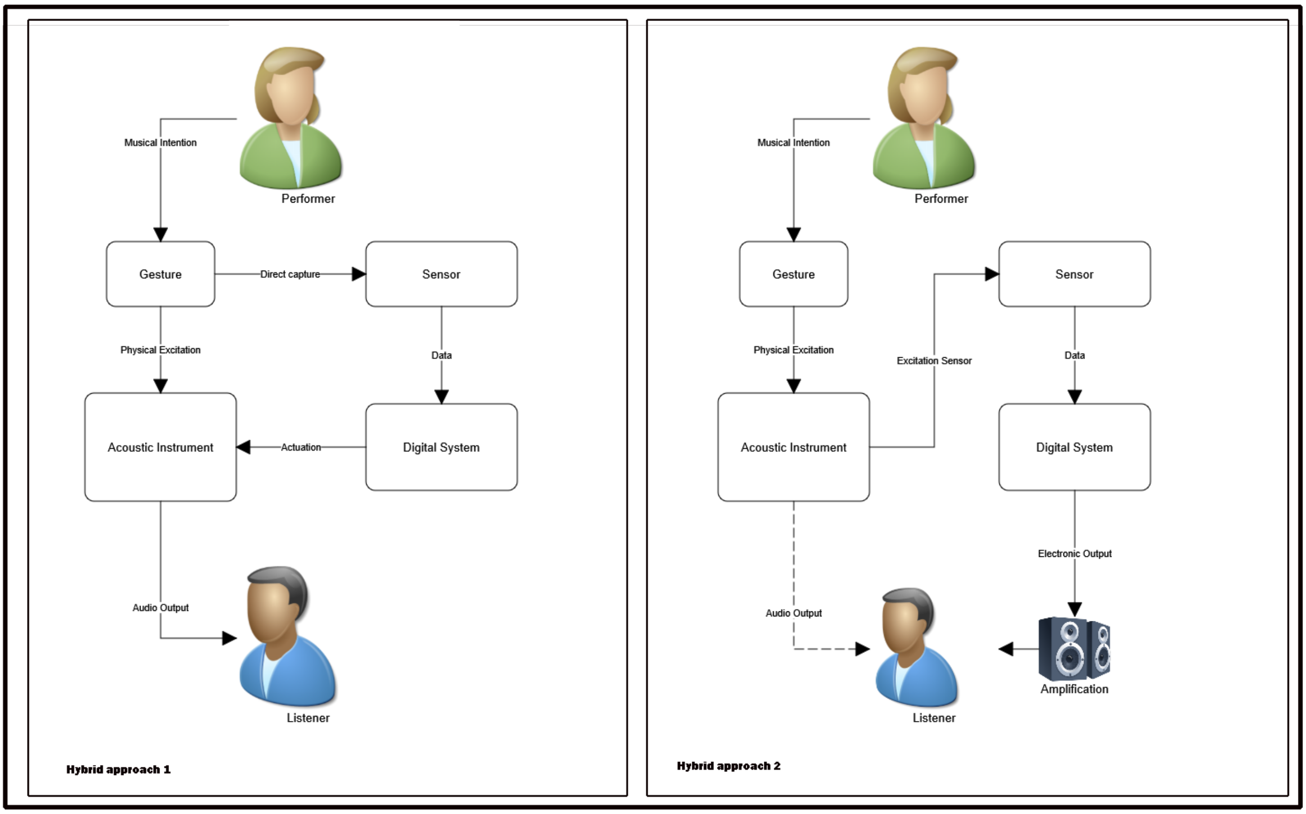

Figure 2.5: Two approaches to hybrid instrument design

output is both acoustic and digital.

Two overlapping approaches of hybrid instruments emerge, as depicted in Figure 2.5.

1. Sensors detect gesture directly and inject a digitally produced signal, either directly or indirectly into the acoustically resonant component of the instrument.

2. The acoustic or vibratory output resulting from player interaction with an instrument is processed or mapped and amplified remotely from the instrument.

It appears that commercial hybrid percussion systems follow the second of these approaches whilst VO-96 manages to achieve both.

2.5 Academic Musical Interface Prototypes

Computationally-Enhanced Acoustic Grand Piano
McPherson and Kim control the acoustic output of an acoustic piano by electromagnetically inducing vibrations in the piano strings via 48 electromagnets . Interaction with the keyboard is detected by the optical sensors in a modified Moog Piano Bar. Amplitude, Frequency (relative to the fundamental of the string) and various phase, enveloping and noise components can be continuously controlled. There is also a pick-up attached to the soundboard which is used for analysis in computationally reinforcing the natural vibrations of the strings [28, 27].

The acoustic output of the grand piano is significantly altered, digitally, whilst maintaining the quality of interaction associated with a traditional acoustic instrument. Gesture vocabulary is maintained and built upon. Once again the string is used as a physical convolution layer.

The EMvibe
This is an actuation system for Vibraphone. Similarly to the VO-96 and the Computationally Enhanced Acoustic Grand Piano, the vibrating element of the musical instrument (in this case the vibraphone bar) is induced into vibration by electromagnetic coils. Unlike iron containing strings, the vibraphone bars are non-ferrous. Magnets have to be attached to each bar. Another significant difference is harmonic qualities of the vibrating element. Vibraphone bars do not support as many harmonics as a string, this makes it unnecessary, and even pointless, to actuate them with high quality audio. Britt, Snyder and McPherson take advantage of this in their simple amplifier design and signal processing. They use bipolar pulse waves, switching between multiple oscillator frequencies to obtain richer harmonic responses from the vibrating bars [8].

This is another example of digital manipulation of an acoustic system in order to take advantage of the natural and rich sounds that the acoustic system can provide, combined with the variation the digital world can contribute. The EMvibe could be used to create a sound source with no other associated narrative, or, in combination with an interface the vibraphone could be controlled by a performing musician.

The Overtone Fiddle
Through a variety of electronic sensors traditional and new control gestures are used to control the audio produced by this instrument. Audio exciters feed processed audio signals into the wooden body of the violin, and a second *floating* body. In this way the acoustic properties of the instrument can be largely independent of

the instruments physical construction [36].

The feeding of digitally processed audio into the body of the instrument is, in this case, aimed at creating a self contained artefact that would not necessarily require an external amplifier. This touches on important aspects of acoustic musical instruments such as collocation of sound and vibrotactility. In this sense the Overtone Fiddle could appeal to musicians who prefer acoustic instruments.

EMdrum

An electromagnetically actuated bass drum is used as a physical convolution layer applied to the signal collected by a microphone. The performer can either tap or strike the microphone to create percussive effects, or sing or play an instrument into it. A moving magnet actuator induces vibrations into the skin of the drum, and a similar mechanism acts as a pick-up for the drum head. Feedback is then manipulated to change the response of the entire system.

Rector and Topel make the point that this electromagnetic induction pick-up/actuation system minimises any alteration to the physical properties of the drum skins, other than through the intended actuation. They point out that the positioning of the moving parts on the membranes of the drums is critical.

The Bistable Resonator Cymbal

Piepenbrink and Wright experiment with a feedback loop combined with DSP to alter the behaviour of an actuated acoustic cymbal. The cymbal is clamped firmly on a rod and suspended from above. The lower end of the rod is attached to an audio exciter. Audio sensing is carried out either via hand-held microphone, which provides the best expressive possibilities, or via a piezo sensor sandwiched between the actuator and the cymbal. They describe a processing chain consisting of pre-amplification, equalisation, gating and compression [40].

The physical set-up - with regard to suspension of the cymbal and the need to hold the microphone (if used) would interfere with traditional playing techniques. Some of the effects described with the Bistable Resonator Cymbal seem to be somewhat unstable. Their project did not go so far as to evaluate with musicians, and they make no mention of reliability of response. This approach is interesting, and in it's early stages, but the target demographic described in section 2.1 will most likely require a more consistent system.

Active Acoustic Instruments for Electronic Chamber Music

Lähdeoja describes a body of work involving *Active Acoustics* applied to traditional musical instruments. Audio rate vibration is driven into the instruments body resulting in air-borne sound. This sound allows for a new character of sound to be added to an acoustic guitar, harpsichord, double bass and tom-tom drum. The main focus of the work is the guitar. He describes a long term design goal as: *"self-contained electro-acoustic hybrid instrument, that is, a single object for input, sound processing and output."* Placement of audio exciters within the instruments is crucial to providing the richest possible sound. A Leap Motion sensor is used to incorporate new control gestures. He has experimented with various pick-up systems, computing hardware and programming languages. The most self-contained version utilised a single piezo pick-up and pure data running on a Raspberry Pi 2 [25].

From the discussion in this paper these instruments are very relevant to the initial problem statement section 1.2. The instruments present themselves as acoustic musical instruments through structure borne sound, collocation of sound, and preservation of established gesture vocabularies and a principle of self containment. They provide variation in sound character and the possibility of new techniques through careful choice of sensors and digital signal processing.

The Silent Drum Controller

Oliver's percussive gestural interface won the prestigious **Guthman Musical Instrument Prize** in 2009. It takes the form of a floor tom with an elastic head and camera to capture it's distortion and map this image to various audio signals in pure data. The contrast between the black drum head and the white interior of the drum assists in the video processing that is used to control sound [33].

The form of a drum has been used here, but little else that an acoustic drummer would recognise. Latencies of 12.5 $\pm$ 2.5 ms are quoted, which are higher than the 10 ms threshold often quoted for musical instruments. The camera was placed outside of the drum, which would make integration with a drum-kit troublesome. Use of camera vision is interesting, if this approach is to be used the camera should be positioned internally.

The Augmented Djembe Drum

Maki-Patola, Hämäläinen and Kanerva mount a webcam with a 70^o viewing angle inside a djembe drum to capture the position and intensity of the shadows cast by the players hands. These images are processed to control the loudness, tempo and timbre of a predetermined computer controlled rhythm pattern. This pattern is made up of layered samples of the djembe used in as the controller. In this way the performer has some level of expressive control over a computer controlled musical pattern. They can also play the djembe acoustically at the same time. The instrument was evaluated by six players with varying musical backgrounds. They were given set tasks and asked to comment freely, as well as answering set questions. The findings showed that the use of a real drum was pleasing to the musicians, and they reported that interaction felt natural. Opinions contrasted over the usefulness of a predetermined rhythm in terms of musical expression; one found it frustrating, another found it the most entertaining aspect. Latency was mentioned as an issue for some of the evaluation participants. Pure data was used as a prototyping tool, but a custom application was made for the evaluated version [26].

Housing the camera inside the drum, and allowing the musician to play the instrument acoustically seem to have been successful strategies. However, issues of latency, the need to light the drum from above, and control that lighting, and the role of the computer as a co-performer are issues that might make this approach less appealing to some musicians.

Hybrid Percussion

Aimi created a set of semi-acoustic physical controllers whose acoustic output was convolved with sampled instruments to produce a variety of expressive outcomes [2]. This consisted of a:

- A cymbal

  An FSR sandwiched between a foam and plastic layers acted as a microphone. Earth hum created when the player touches the cymbal was filtered out, but used to create a muting affect.

- Brushes

  Piezo pick-ups were attached to the root end of the brush wires and the acoustic signal was sent wirelessly to the system. Other brushes incorporated bend sensors

- A frame drum

  Fitted with FSRs to detect damping and contact microphones for audio.

- Bass drum

  Vibration was picked up with piezo film elements picked up the vibrations. Sound was fed back into the drum via a speaker system. A mesh head was used to reduce feedback.

This was one of the few cases where the research included evaluation by professional musicians. He used a combination of set questions and informal interview, and allows the experts to freely explore the instruments. It is apparent from Aimi's observations that different musicians have differing approaches and requirements. He noted that experts could perform with latencies of up to 40 ms, and were concious of latencies over 15 ms. A number of the musicians involved in his study were particularly interested in interaction involving damping of the drum.

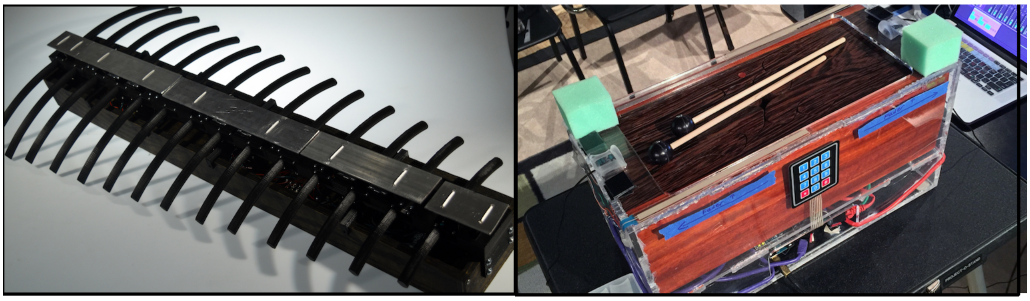

Figure 2.6: From the Guthman Musical Instrument Competition 2017
Left: Ribcage
Right:Logdrum+

2.6 The Guthman Musical Instrument Competition

The Guthman Musical Instrument Competition has been taking place at Georgia Technological College every year since 2009 seeking to find the best new idea in music technology. This competition is not restricted to electronic or digital instruments and as a result includes interesting and diverse approaches to instrument design with contestants from the arts and technology as well as academics and enthusiasts [19]. This year (2017) there were a number of inspiring contributions including:

- Ogata's **Ribcage**

  This consists of printed ABS *ribs* running along either side of a series of robotically actuated xylophone like bars. The ribs can be struck or bowed. The instrument makes extensive use of high quality contact microphones that were carefully placed to avoid damping resonances in the instrument. Ogata's aim is to blur the boundaries between the human performer and the robot.

  A high degree of expressive performance is possible on this instrument as was demonstrated by Ogata himself at the competition. The instrument has a strong acoustic element, but it does not resemble existing instruments, which might not appeal to this project's demographic. It also requires external amplification, and relinquishes some rhythmic control to the computer. See Figure 2.6.

- Asman's **Logdrum+**

  An augmented logdrum uses high quality contact microphones, FSRs trapped under pieces of sponge, a numeric keypad and Max/MSP to provide pitch change and granular synthesis manipulation of the acoustic output of the drum.

Interaction with Logdrum+ is substantially unchanged by the augmentation. All digital manipulation is controlled via the touch-pad and FSR interfaces. The use of sponge covered FSR sensors as a control surface was visually understandable from an audience perspective, and allowed for expressive control. Interaction with the logdrum whilst interacting with the FSR interfaces seemed difficult, if not impossible. See Figure 2.6.

Use of high quality contact microphones proved to be an effective way of capturing audio from these instruments, but could prove prohibitively expensive for this project.

2.7 Design Models

There are a number of approaches to defining frameworks for design and analysis of musical interfaces. They range from propositions for dimension space representations [7] to simple lists of design principles [11]. There are many aspects to consider from the role of the computer to the stakeholders and their interdependencies. It is beyond the scope of this work to provide an exhaustive review, but in the sections that follow some relevant principles are outlined.

2.7.1 The Instrument

Miranda and Wanderely [29] list a number of ways to define a categorisation for new musical instruments ranging from the number of people playing the instrument to the physical distribution of components (from self contained to internet based networks). They favour a continuous system that makes a general similarity comparison between the new instrument and existing instruments. In this system labels range from **Augmented musical instruments** *e.g.* Gen 16 (see section section 2.4) to **Alternate Gestural Controllers** *e.g.* Ribcage (section 2.6).

Tanaka defines a number of ways that musical instruments and design approaches can be framed.[45]. Some of the more relevant concepts are listed below.

- Open Ended Systems

  This approach considers the instrument as a series of components; Input device, Mappings, Sound Synthesis, Output System. Questions arise from this model such as *is the instrument just the physical artefact, or does it include the software?*. These questions are less apparent with an acoustic instrument as the outcome of interaction is a function of the physical object.

- Controllers

Here the hardware interface is considered as the instrument in it's entirety. Consider the case of the controller keyboard which can be considered to be the same instrument whether it is controlling a vst guitar or a MIDI drum synthesiser. This way of thinking has led to some novel instrument designs, but a musician who has spent years mastering an acoustic instrument will not necessarily be attracted to a completely new interface, where their gesture vocabulary is not directly applicable.

- Hyperinstruments

  A traditional musical instrument which has been extended or augmented. The acoustic musician' skill bank will effectively be leveraged here, providing possibilities for new sounds and or new techniques without the need to first learn a new instrument.

- Audio as Sensor

  Rather than directly detecting a physical gesture, audio itself captured and used to directly shape musical output. This approach fits well with hyper instruments and can be an important feature of hybrid instruments, as described in section section 2.4.

O'Modrhain refers to three perspectives from which an HCI system can be viewed [34].

- The System

  The perspective of the hardware or software designer

- The User

  The performers understanding of how the instrument behaves

- The design model

  The way the designer represents the system to the user

These perspectives are useful for both design and evaluation. (See section section 2.8.)

2.7.2 The Role of the Computer

Emmerson [17] outlines two, sometimes concurrent, concepts for the integration of digital music into the acoustic instrument paradigm:

- The musical output is in entirely under direct bodily control of the human performer as if it were an acoustic instrument. *e.g.* Triggering samples.
- the computer acts as a co-performer. *e.g.* Perc Pro.

This second paradigm can be further divided:

- The computer performer is a near clone of the musician, applying a simple transformation such as a delay
- The computer is independent of the musician, such as a drum machine

These models represent a range of possibilities that digital instruments can provide. Care should be taken to present these options to the acoustic musician without causing confusing or frustration as was the case with some of the musicians in the case of the Augmented Djembe Drum described in section section 2.5.

2.8 Evaluation Models and Frameworks

Barbosa, Malloch and Wanderely [4] carried out a review of evaluation methods used in the **New Insterfaces for Musical Expression** (NIME) community over the period 1012-2014. Their findings revealed a number of different understandings of what evaluation might mean and widely varying, sometimes poorly defined goals and targets. There were also a significant number of projects where the word evaluation was missing from the report.

They acknowledge evaluation goals, targets and stakeholders vary depending on the nature of project in hand but argue for more clarity. The question raised by the paper is not *should we evaluate?* but *how?*, and *how should the results be used?*.

O'Modhrain presents us with a framework for evaluation [34] which accounts for the multiple perspectives that can be adopted in DMI appraisal. In addition to the models described in subsection 2.7.1, three frameworks are outlined:

- Evaluation of Performance – the Audience Perspective
- Evaluation through practice – the Performer's Perspective
- Evaluation of Interaction – the Designer's Perspective

It is often and convincingly argued that the performer's evaluation is the most critical when considering a new musical instrument. If musicians don't like the instrument it will not be played. As a result many evaluations understandably place focus on this aspect. The least attention is paid to the audience perspective [4].

One perspective that has not been addressed by any of the literature that the author has reviewed is that of the co-performer. This perspective is likely to share attributes with the performer and audience perspectives, but may reveal some interesting insights.

Data derived from evaluation can be either qualitative or quantitative. With regard to quantitative data, various **Human Computer Interaction** (HCI) tests have been adapted for use with DMI. In a previous project [50] an adapted **System Usability Scale** (SUS) test was used to evaluate a digital shaker. Using the same test on the artefact created from this project could potentially give more meaning to the data obtained in both these projects.

Obtaining qualitative data can also prove problematic. A number of recent studies have made use of an evaluation of violins carried out by Saitis, Giordano, Fritz and Scavone [43]. This study aimed to find out more about the evaluation process that naturally takes place when musicians try out new instruments. In the process of this study a list of descriptors used by violin players when discussing the quality of instruments was compiled. Some of these descriptors have since been used in constructing tests for evaluation of other instruments [22, 50].
Considerations such as instrument and genre specificity were not addressed and perhaps should be considered.
It would good practice to build upon the author's previous evaluation protocol in order to establish a routine approach.

2.9 Final Problem Statement

Despite the many creative possibilities that electronic percussion can provide, our target demographic still prefers an acoustic instrument. There is no shortage of electronic drum kits for them to choose from, but these kits rarely provide the nuanced level of control, familiarity and aesthetic appeal of a traditional drum kit. Those that come the closest are the hybrid designs, particularly the Gen 16 and the simple use of triggers. The Wavedrum, V-drums and DDrum also provide nuanced control, and some degree of acoustic *feel*. These approaches require external amplification, which results in a dislocation of sound and gesture and presents practical issues such as transportation and the ability to judge the balance between acoustic and electric signals.

Hybrid systems seem to offer a solution to some of these issues, especially those where the electronic signal is transferred to the body of the instrument. Yamaha's hybrid piano provides an impressive model, where the acoustic properties of the instrument are completely unrestrained, all the sonic possibilities of digital keyboards are available and the sound is propagated and convolved by the acoustic body of the instrument. The EL Cajon by Roland comes close to this, they have opted for a loudspeaker mounted in the front of the instrument rather than exciting the body of the cajon directly, and have chosen to only trigger samples. This may reduce the subtlety of control over the digital sounds, but as the cajon still functions acoustically, the instrument as a whole retains the ability for nuanced control.

By using the hybrid design paradigm and applying it to a snare drum, thus placing an alternative electric and acoustic instrument at the centre of the kit drummers world, it may be possible to provide the acoustic drummer with some of the advantages of electric percussion in a way that is intuitively accessible, aesthetically pleasing and useful to them.

> Design a hybrid, **D**igitally **A**ctive snare **Drum** (DAD), designed for acoustic drummers

2.10 Succsess Crtieria

The prototype of DAD should meet the following criteria:

- Function as a parametric snare drum.
- Serve as a snare drum in a group playing situation.
- Provide expressive possibilities beyond that of an acoustic snare drum.
- The acoustic properties of the snare drum should be maintained.
- Appeal to the target demographic.

Expert evaluation will be used to find out if the success criteria are met. The performer will be considered the ultimate arbiter of the evaluation, but perspectives other than the performer will also be sought where appropriate.

Chapter 3

Design and Implementation

3.1 The Snare Drum

The snare drum in the form of the *tabor* dates back to at least the twelfth century when it was commonly depicted in a marching, one-man-band setting of drum and flute [42]. By the nineteen-thirties the drum kit was well established, and although details of drum sizes, materials stand configuration have changed, the snare drum has remained, both physically and conceptually, at the very centre of the instrument.

A snare drum (see Figure 3.1) is made up of a shell, a snare mechanism and two skins, which are also known as heads.

The shell can be made of a number of materials including wood, steel, copper, brass, bronze and aluminium. Most, but not all feature a vent hole, originally designed for humidity equalisation, opinion is divided about it's acoustic impact. The shell can also vary in depth.

Drum skins were originally made of stretched animal skin. Most snare drum skins are currently made of one or more layers of polyurethane, the thickness and number of layers affects the acoustic properties of the skin. Plastic heads are more stable with regard to atmospheric changes, and easier to change, being held in place with metal hoops and tensioning bolts rather than being tied in place with ropes.

The snare mechanism, which gives the snare drum it's name and characteristic sound, is made up of a set of strings or wires that are held over the lower, resonant head and tensioned by the snare tensioner. When the upper, batter head is struck, a shock wave sets the resonant head into motion resulting in the snare wires rattling against it. The tuning of the resonant head, the materials used and the number and tension of the snare wires all affect the sound of the drum. An unfortunate side effect of the snare mechanism is that it can resonate in sympathy with external noises such as those from a nearby bass guitar amplifier. To prevent unwanted snare rattling due to extraneous noise, or for musical effect, the snare

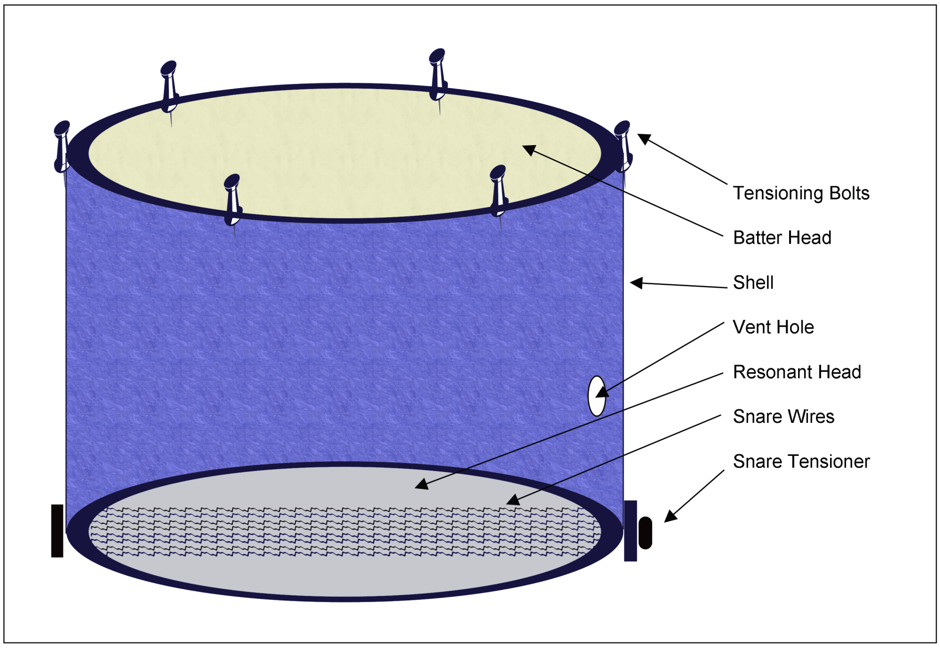

Figure 3.1: Anatomy of a snare drum

mechanism can be disengaged with a lever.

There are numerous techniques that can be used to play the snare drum. Some are listed in [46], but that list is far from exhaustive. Even within a single effect, such as a rim-shot, there can be more than one way of achieving the desired sound. For this reason any attempt to detect a specific effect by tracking position of stick or hand will be beset with difficulties. Equally, more general techniques such as using brushes or sticks can also vary extensively from drummer to drummer. These factors should be taken into account during the design process.

3.2 The Physics of a Drum Skin

It is possible to consider a drum skin under tension as being similar to a two dimensional string in a musical instrument; waves rebound, cross and re-cross each other and form natural standing waves accordant to the resonances of the drum.
Concentric modes are made up of one or more concentric circles. Diametric modes are defined by dividing the drum with any number of diametric lines with even angular distribution. Adjacent regions of the drum head move in opposite directions (See Figure 3.2). The striking position therefore has a marked effect on the perceived tone of the drum as it can dampen, or excite combinations of these modes. Further to this, the concentric modes, which are more easily excited by striking the

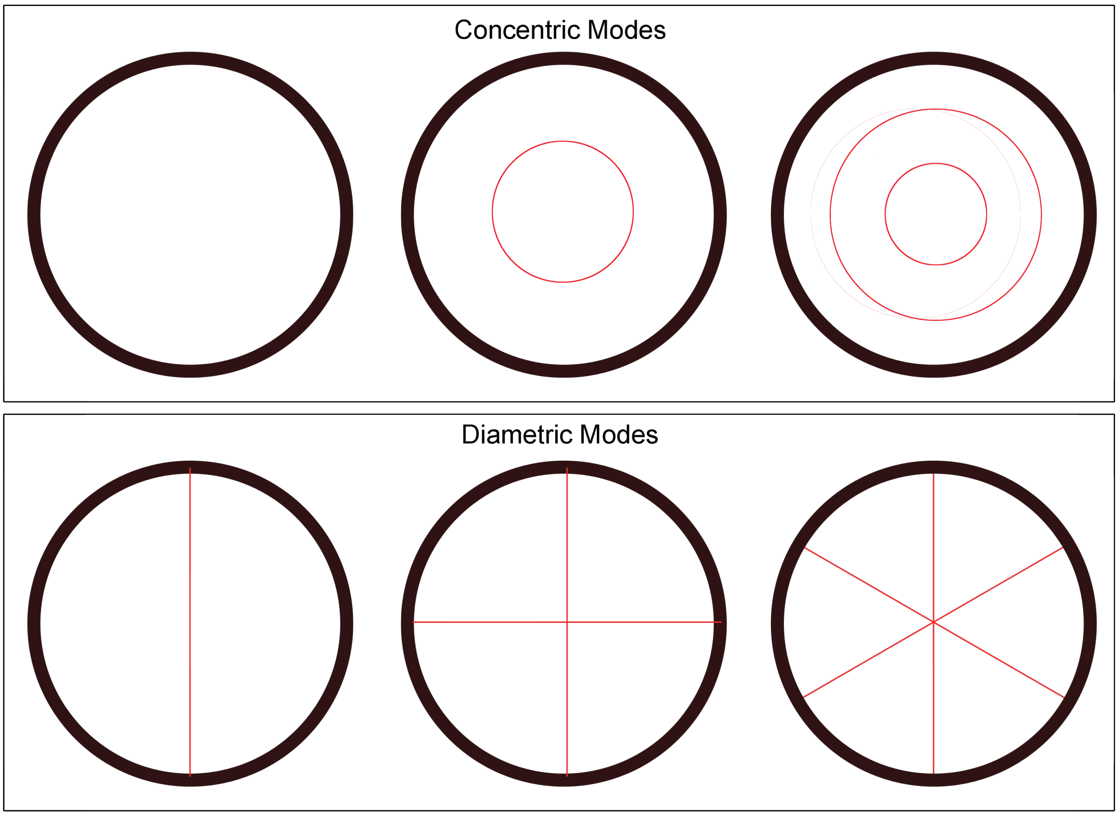

Figure 3.2: Mode formation in a circular drum skin

centre of the drum, decay far more rapidly. This results in a longer decay when the drum is struck toward the edge. [10]. This could be a potentially useful method for detecting the striking position of the drum, and thus providing some interesting mapping possibilities. The frequency relationship between modes is not the same as that found in a vibrating string, and this should be considered in any synthesis algorithm.

The weight and stiffness of the striking object obviously has a direct effect on the amount of energy transmitted on excitation. This may be a doorway to determining what type of beater has been used. The weight is proportional to the energy transferred to the skin as can be seen in the well know equation below.

$$E = \frac{1}{2}mv^2$$

3.3 Initial Interviews

Before defining specific design requirements some further research into construction, physical behaviour and playing techniques was undertaken. A series of preliminary, informal interviews were conducted with professional and amateur drummers, the notes for which can be seen in Appendix B. This was done, with the observations outlined in the preface regarding the relationship between designer and performer in mind, to shine a light on what specific benefits an active snare drum might provide for the demographic specified in section 2.1, and to avoid falling into the trap of designing an instrument for the designer.

The interviewees were informed of the general goal of the project and ideas were proposed and constructively criticised by both designer and drummer. Some key suggestions are listed below.

- Division of the batter head into regions with different responses.

  Opinion as to how this should be divided varied from drummer to drummer.

- Respect for the centre of the drum as it is the main working area.
- Respect for the batter head in general, preferably no damping of it's natural resonances.
- Allowance for different techniques (See section 3.1).
- The ability to change the sound of the snare drum, but still have it sound like a snare drum.
- Creating new techniques to control unusual effects was proposed, but most drummers doubted that they would find a use for it.
- Preventing unwanted sympathetic resonance from the snare mechanism.
- Easy access to parameter controls.
- The ability to easily switch the digital component off, or on. (See section 2.4).
- Amplification of brushing technique
- Preferably no external amplification.
- The ability to balance and blend the acoustic and digital sounds.

3.4 Related Technological Research

3.4.1 Sensors for Gesture Capture

There are a variety of tools and techniques available for gesture capture that have been applied for percussion in addition to those that have already been mentioned in this report. Tindale, Kapur, Tzanetakis, Driessen and Schloss [47] provide a comprehensive list of working methods. The most common commercially used sensors have been piezos and FSRs.

Sokolovskis and McPherson [44] experimented with a method for locating the position of a strike on an acoustic drum head. By using six near field optical reflective sensors concentrically under the batter head of a snare drum and using a *time of difference of arrival* (TDOA) algorithm, strikes were located to within a two centimetre accuracy. They did not implement this in real-time, but state that this would be a possibility, with the caveat that onset detection should be improved before a performance ready version could be implemented.

Aspects of Sokolovskis and McPherson's approach sound promising, but techniques such as flams, rolls, muting and rim-shots would likely give false readings with this TDOA recipe.

Buchla registered a patent in 1999 which described a dense system of electromagnetic transmitters and receivers designed to measure multiple simultaneous pressure deformations in a specially coated, reflective membrane. The sensor readings were to control a drum like synthesis [9].
Such a system would overcome the problems that might be encountered with TDOA, in that flams, rim-shots, muting techniques etc. could be detected accurately. However, a great number of sensors would have to be used, and the need for a special reflective coating would present problems beyond a prototype in that specially made drum-skins would be required if the drummer wished to change an old batter head.

3.4.2 Computing Hardware

A common prototyping approach is to use a micro-controller as a bridge between sensor and the hardware producing or processing the audio output. McPherson Jack and Moro investigated the latencies of a number of commonly used configurations to see if they match up to commonly accepted benchmarks for music performance. A commonly quoted threshold is 10 ms. They discuss the performance of Arduino Uno, Teensy, Raspberry Pi and Bela Beaglebone systems. Bela came out on top with sub millisecond latency and 20 μs jitter [30].

3.5 Design Requirements

- Low latency

  The commonly accepted threshold for acceptable latency is 10 ms [49]. It has been noted that the minimum acceptable latency depends on the application, and that jitter is more significant in the ability to control a musical instrument [50, 30]. With regard to percussion instruments the best practice is to keep both latency and jitter as low as possible. The Bela platform outperforms all other options reviewed in this paper.

- Collocation of sound

  As noted in section 2.5 and Table 2.1, collocation is considered as one of the advantages of acoustic instruments, indeed it is one of their defining qualities. This could be achieved by mounting a speaker directly in the drum, or by actuating the drum with an audio exciter.

- Choice of technique should not be obstructed by the digital augmentation of the drum.

  As noted in section 3.3 and section 3.1, drumming techniques are numerous and vary from drummer to drummer. Accounting for this is essential. This does not necessarily mean that different techniques should be mapped individually.

- Striking the centre of the batter head should produce a snare like sound.

  This is essential if DAD is to function as a snare drum. Many commercial products attempt to give the musician a variety of sounds modelled on variants within the same instrument type. Expanding this concept to extend the snare sound into new dimensions would provide the variety associated with EP in a format recognisable to the acoustic musician.

- As noted in section 3.3, different areas of the drum should produce different sounds, and this should be assignable.

  This could be achieved using TDOA, though as noted in subsection 3.4.1 certain techniques could cause errors. Timbral analysis is another potential approach, although this could result in strongly contrasting responses for different techniques. Direct sensing with piezo discs is potentially the simplest approach, but would result in some damping of the batter head.

- Aesthetics

  Whilst this is subjective, maintaining the appearance of a traditional drum should prove appealing to a demographic that, by definition appreciate that design. Having any parametric controls close to, or on the drum, as with Syndrum and the Moog 1130 (section 2.2) should increase the sense of DAD being a self contained instrument, and keeps with traditions seen in electric guitars and keyboards.

- Variety of digital audio signals.

  In order to present the possibilities of electronic percussion a variety of sounds and approaches should be provided. This should be carefully chosen to avoid an overwhelming experience in evaluation, but still present varied options.

3.6 Initial Experiments

Audio Exciter and Piezo Disc Placement

Various components were tested to determine what impact they might have on the acoustic qualities of a snare drum. These included piezo discs and two models of audio exciter. It was found that any of these items in contact with the batter head significantly reduced the resonance of the drum. The audio exciters, when placed on the resonant head seemed to have little affect on the sonic characteristics of the drum. The larger and more powerful model of the audio exciter models was selected for further use. Interference with the function of the snare mechanism was not considered until late in development as it was not a foreseen requirement. It was later discovered that the audio-exciters did indeed prevent the conventional action of the snare wires.

Piezo Shell Pick-up and Microphone Experiments

The use of audio as sensor (see subsection 2.7.1) was attempted via a piezo pick-up attached to the drum housing, and via an electret microphone and pre-amplifier circuit, both situated inside a snare drum. The signal from both types of sensor contained a significant level of noise making them of little use for direct amplification and output, and problematic for analysis. The high noise level was most likely due to a combination of the quality of the microphone, pre-amplifier and the steel shell of the drum acting as an aerial.

Optical Sensor Tests

A single QRE1113 optical sensor and circuit was temporarily placed under the batter head and the signal auditioned, and viewed in the oscilloscope facility provided by the Bela *Integrated Development Environment* (IDE). The resulting signal contained noise, but was a cleaner signal than either the piezo or microphone had provided.

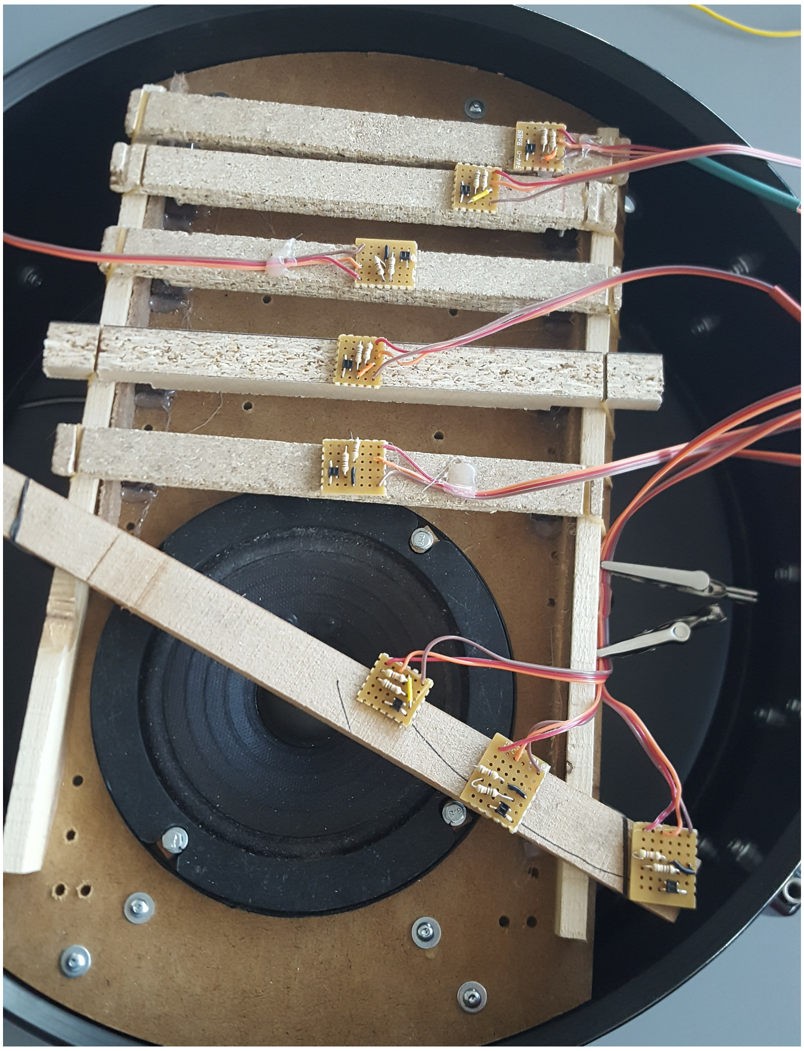

Figure 3.3: QRE1113 sensors in an acentric arc

3.7 Preliminary Design

A preliminary design (see Figure 3.4) was made consisting of a shop bought snare drum customised to contain an upward facing loudspeaker, an acentrically placed arc of eight optical sensors, all necessary processing hardware, an audio amplifier and two audio exciters placed on the inside of the resonant skin.

There were two reasons for the acentric arrangement of optical pick-ups (see Figure 3.3). One was to minimise the chance of multiple pick-ups being placed at nodes. (See section 3.2.). The other was to facilitate an approach to TDOA positional strike detection that would be less prone to confusion from techniques such as flams. A theory was formulated that if an onset was detected at all pick-ups within a short time frame, then the strike position must be close to the centre of the circle described by the arc of sensors. This approach would allow one area of the batter head to be mapped differently to the others.

3.8 Hardware

A schematic of the entire DAD system can be seen in Figure 3.5

Processing Boards

Bela Cape

Bela Cape and Beagle Bone Black were chosen for low latency and availability of audio-rate analogue inputs.

This system provides a number of advantages:

- A browser based IDE which includes an oscilloscope to assist development.
- 8 Analogue inputs that can be read at audio rate.
- Audio in and out ports
- C/C++, Puredata, or Faust can be uploaded via the IDE.

The analogue inputs are polled sequentially every cycle. The sample rate and block size can be editted via the IDE. It was discovered during development that in order to increase the block size, the sampling rate has to be increased, each time the sample rate is double the number of available analogue inputs is halved, as the polling rate remains constant.

Arduino Mega

An Arduino Mega is also used to expand the number of analogue inputs such that two potentiometers, in conjunction with some push button switches, can be used to change various user parameters. This facility was also useful in developing software.

Sensors

Eight QRE1113 Minature Reflective Object Sensors as used in [44]. Only two of these sensors are active in the prototype tested. (See Figure 3.4.).
In order for synthesis output to be of a high enough quality, and for onset detection to function reliably, it was found that the operating sample rate and block size of

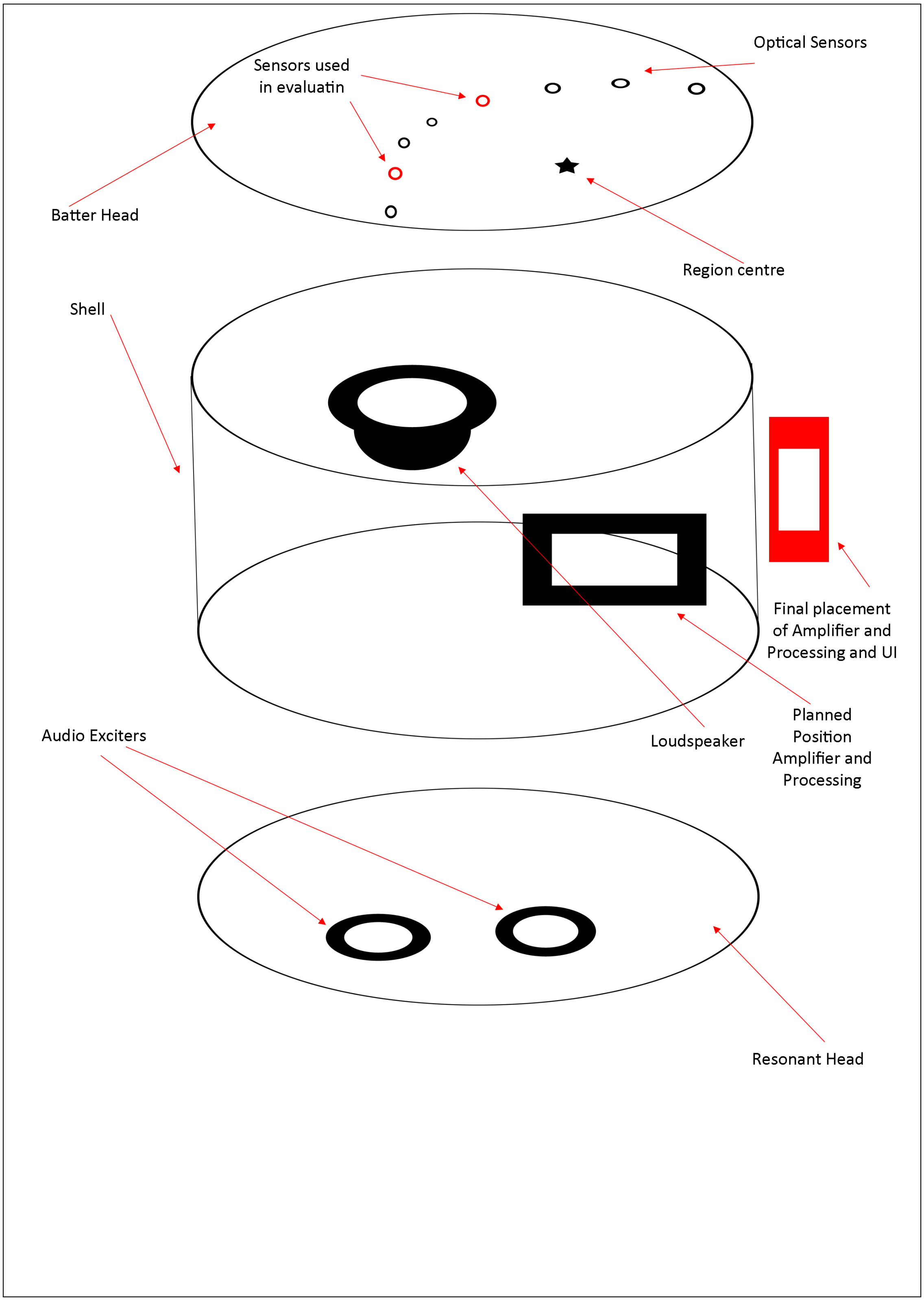

Figure 3.4: Preliminary Design for DAD

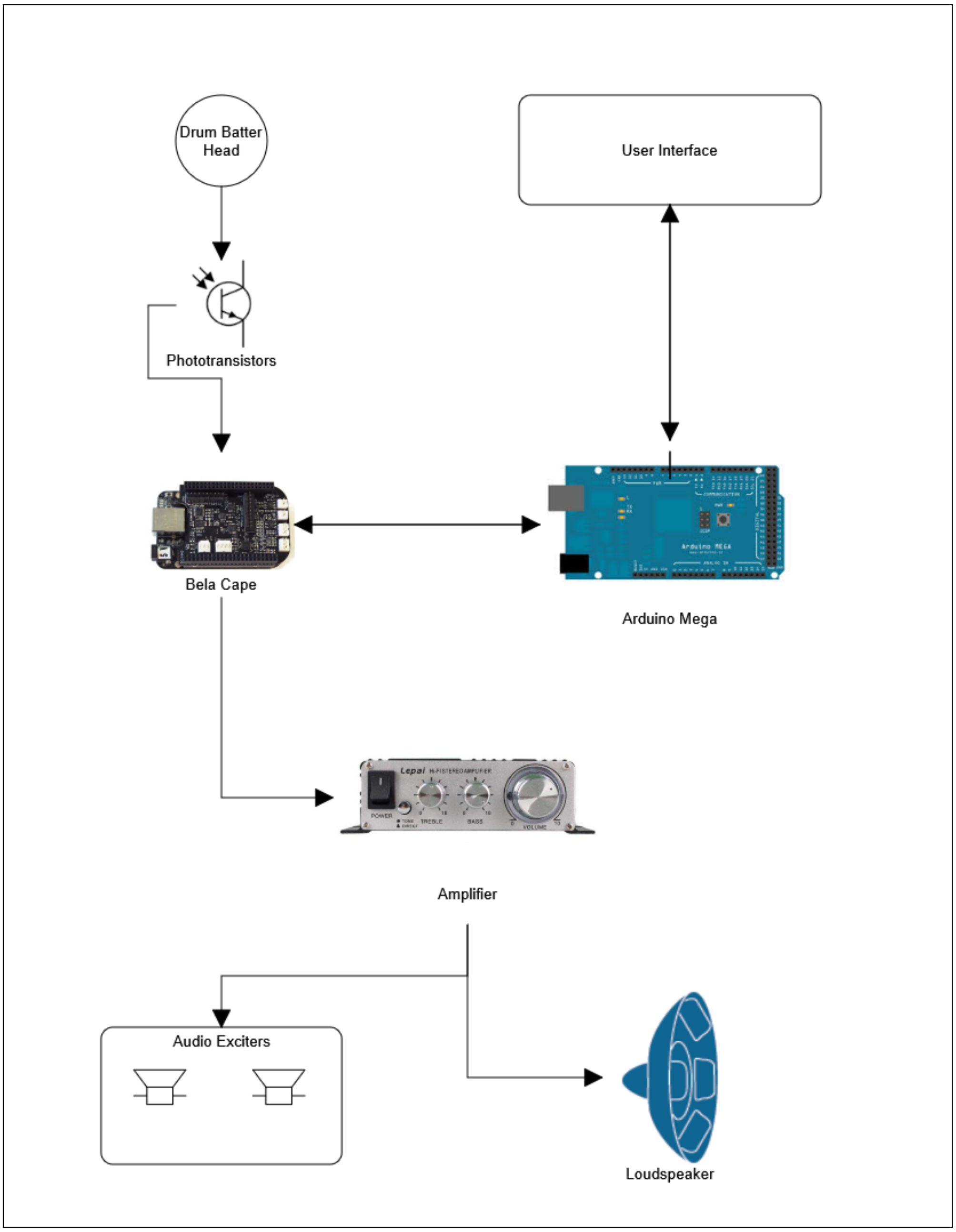

Figure 3.5: Schematic of DAD hardware sytem

the Bela Cape had to be optimised. In order to maximise performance the number of active analogue inputs had to be reduced. For this reason TDOA methodology was dropped, and only two pick-ups were used.
Rise time is approximately 20 μs. These sensors were chosen because they have proven effective in other related research, and they have the advantage of not restricting the movement of the batter head [37, 44].

Audio Output

All these components were used as they were readily available and were deemed to broadly meet requirements:

- Two Dayton Audio exciters with a nominal impedance of 4 ohms and a power handling of 20 watt RMS were connected in series and attached to the drum's resonant skin with double sided adhesive tape.
- A disused Pioneer B11EC80 50 watt mid range speaker from a *Acoustic Image* acoustic instrument amplifier.
- A Lepai LP 2020A 20 watt audio amplifier.

Manufacturer's frequency responses for the audio transducers (loudspeaker and audio exciters) can be seen in Appendix D.

3.9 Physical Build

DAD is built from a shop bought snare drum in order to ensure the acoustic instrument meets a minimum standard.
A laser cut MDF frame is bolted to the inside of the drum shell using the existing tuning bolt housings and is braced at either edge with a rectangular cross sectioned strip of wood. The loudspeaker fits into a hole cut into the wooden frame, and is held in place by bolts threaded into nuts trapped in a circular bracket. Figure 3.6.

The eight optical sensors were mounted on thin wooden slats, which are elasticated in place with height-adjusting bolts positioned underneath them (see Figure 3.3). This allows fine adjustment of position relative to the batter head.
Two audio exciters are adhered to the inside of the resonant head.
Wires from the sensors and audio transducers are fed through the vent hole in the drum shell.
The Bela Cape, Beagle Bone Black, Arduino Mega, push buttons and potentiometers are housed in a laser-cut and laser engraved housing, which is bound to the outside of the drum with elastic strips. This unit acts as a *User Interface* (UI) Figure 3.7.

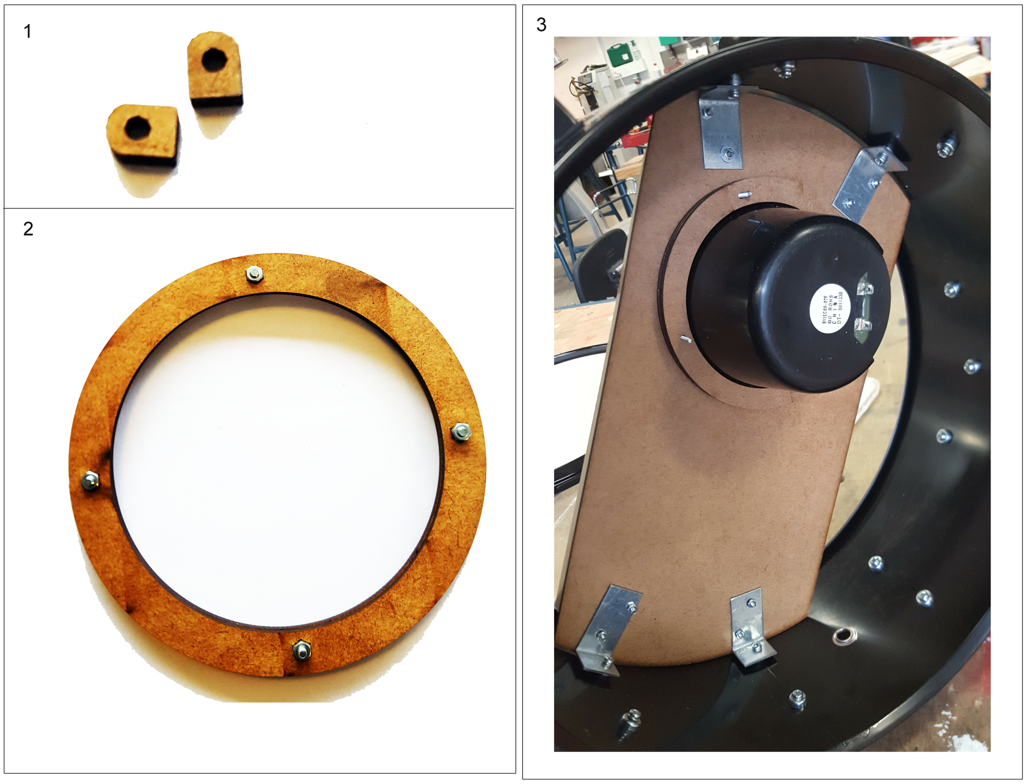

Figure 3.6: Speaker Bracket System
1. Nut retainers
2. Laser Cut Bracket
3. Speaker Frame in Position Inside DAD

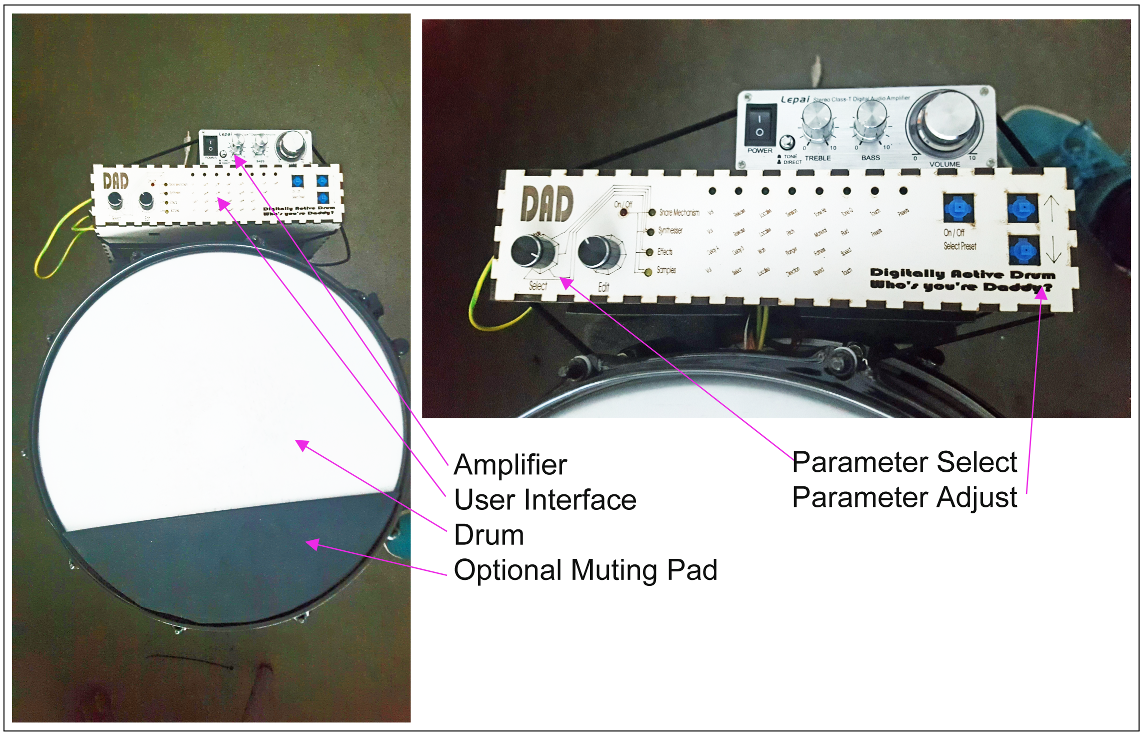

Figure 3.7: Players view of DAD

Particular regions of the batter head are outlined in marker pen applied to the inner surface. The markings take the form of three concentric circles. These are intended to give an indication of which areas of the drum might behave differently, and give the impression that these areas are not fixed in diameter.

3.10 Electronics

The optical sensors are each mounted on a small piece of stripboard, each piece of board is comprised of the circuit depicted in Figure 3.8. The negative terminals of the sensors circuit are unified within the drum and a 100 μF capacitor is placed between the earth and positive rails at this point.

3.11 Programming

Readings from two of the eight optical sensors allow the performer to control various synthesis, sample playback and audio effects whilst playing the acoustic drum. Only two of the eight sensors were used during evaluation for reasons explained in section 3.8.

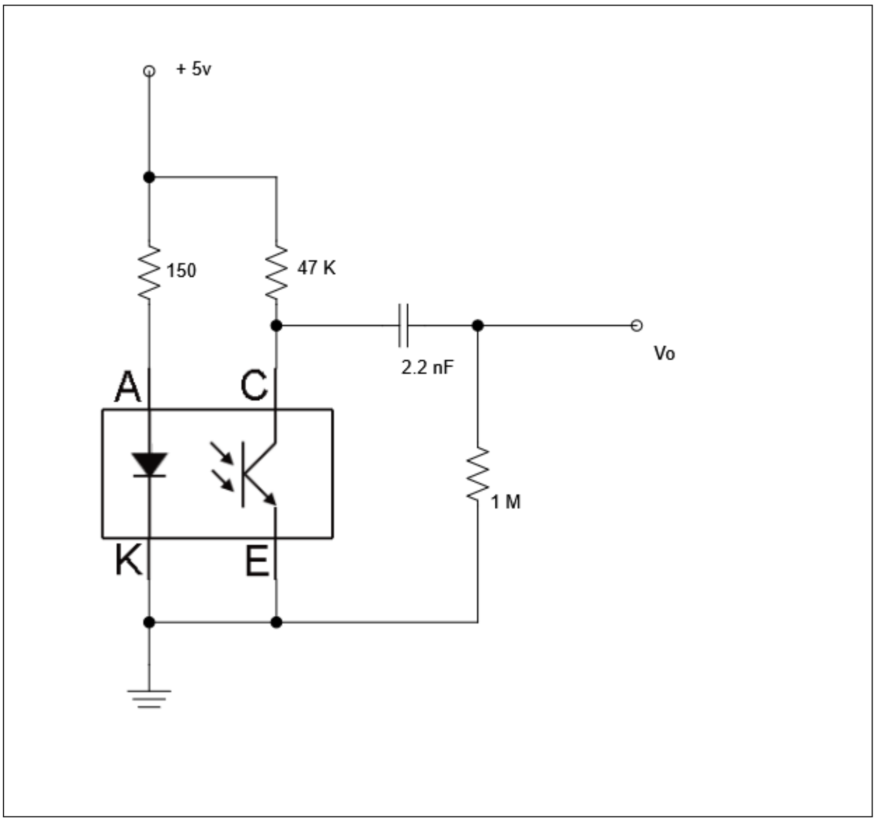

Figure 3.8: Circuit for the qre1113 phototransistors

The performer can make adjustments to DAD's behaviour via the UI which receives input via two potentiometers and three push buttons. This interaction is relayed to the Bela Cape and Beagle Bone via an Arduino Mega.

A coarse overview of the DAD pure data system can be seen in Figure 3.9.

3.11.1 Synthesis, Effects and sample triggering

The synthesis, effects and sample playback are carried out in pure data.
In keeping with the practice observed in commercially available EP an emulation of snare mechanism and drum acoustics is provided. It is not intended that a *life/like* sound should be produced, but rather a sketch of how realistic sounds could be used and adjusted, and within the same set of controls more outlandish sounds could be dialled in, such as extremely long snare mechanism delay times. It was hoped that this would provide a familiar model at the same time as allowing for artistic exploration of the possibilities of digitally created sound.

Snare Mechanism

The snare mechanism module is developed using Cook's *Physically Informed Stochastic Event Modelling* (PHISEM) algorithm as starting point [12].
The signal from the centre sensor is first hi pass filtered with a cut off frequency of 150 Hz. This removes D.C. and some 50 Hz noise. It also reduces the effect of high sensor signal amplitude that was found to occur when playing the drum by hand. This effect was controlled rather than eliminated as it was considered to be novel and musically interesting.
The signal is then raised to a user variable power. This has the effect effect of making the pick-up more or less sensitive to strike events occurring in close physical proximity to it.

The root mean square (RMS) amplitude is then calculated. Experimentation revealed that a pure data block size of 64 samples gave the best results. This amplitude is then fed into the PHISEM based algorithm:

A white noise signal is used to generate random impulse signals. The resulting signal has a user defined amplitude envelope applied to it so as to model a series of collisions of small particles. This is further processed by a user defined filter to give the impression of different materials being involved.
The signal is then finally amplitude modulated by a sawtooth wave. The frequency and gain of the sawtooth modulation can be adjusted via th UI. The concept behind this feature is that it models the snare wires repeatedly hitting the resonant head at a rate dependant on their tension.

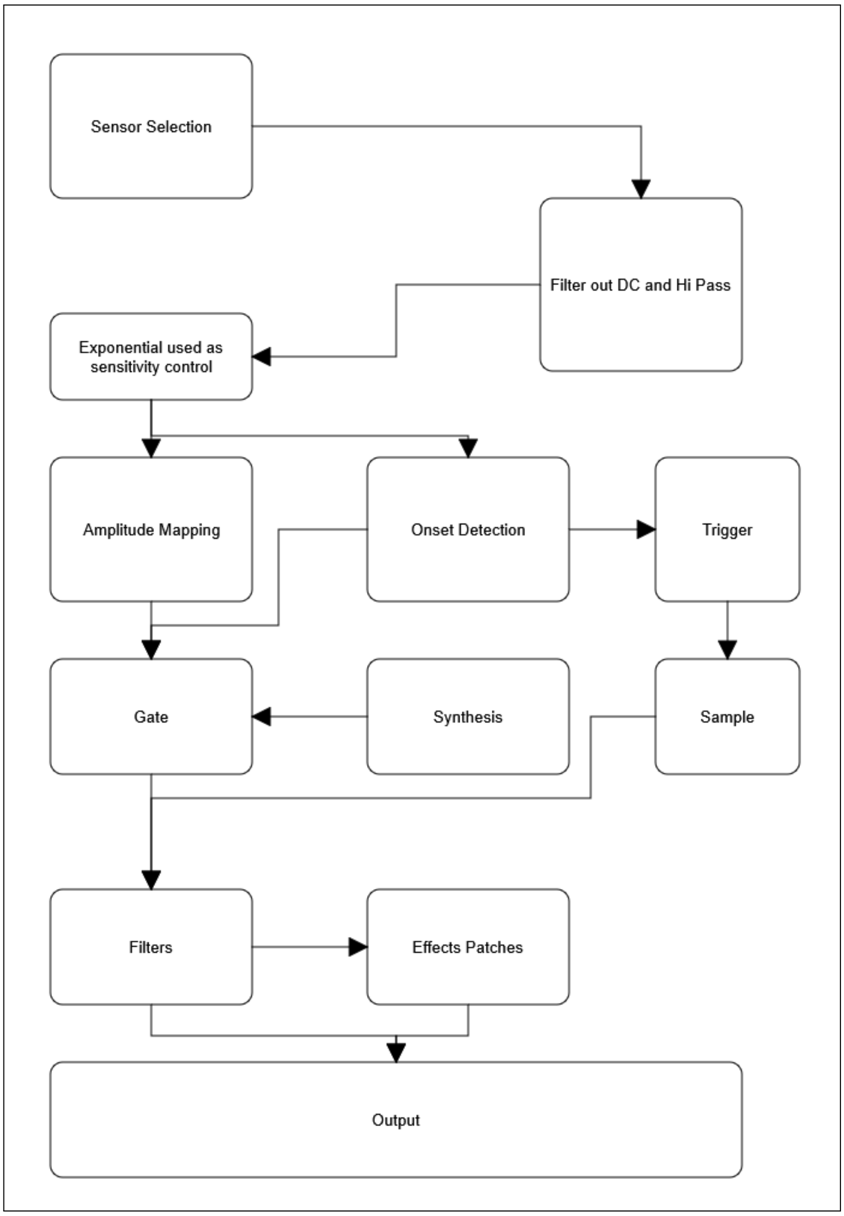

Figure 3.9: Overview of the Pure Data patch used in DAD

Subtractive Synthesis

The Signal from either sensor is selected by the user, and high pass filtered with a cut off frequency of 100 Hz. This filters out D.C and reduces 50 Hz interference.
A user controlled gain acts as a sensitivity adjustment before the signal is sent to the pure data object; *bonk∼* which detects percussive onsets by looking for changes in spectral composition rather than changes in overall amplitude [41]. This means that it is less likely to report false positives, or have false negatives that would otherwise be triggered or masked by the ringing of the acoustic drum or output from the synthesis algorithms.
The amplitude of the onset reported from *bonk∼* is used to create an amplitude envelope for the synthesised sound.

The subtractive synthesis model is built from one sawtooth wave that is filtered by three narrow band pass filters. The centre frequency of the lowest filter and the mathematical relationship between it and the other two filters can be changed via the UI. The width (and consequently the resonance) of these filters can be adjusted and their centre frequencies can also be swept by a sine wave. This module has the affect of sounding like a struck material, where the qualities of the material can be changed by the variable parameters. When fed into the drum it takes on the physical resonance of the instrument and blends into the acoustic sound.

Sound Effects

The following patches were developed to provide a variety of the possibilities of EP, without providing so many options as to exhaust or overwhelm subjects during evaluation.

Ping Pong Delay
Delay is a commonly used effect found. It provides a computer as performer option for evaluation See subsection 2.7.2.
The output of the snare mechanism and subtractive synthesis modules can be sent to two delay lines which are connected in series to create a ping pong delay. The output from each delay is sent to a different output (loudspeaker or exciters). The length of these delay lines can be controlled via the UI.

Flanger
Flanger was chosen as quick to implement effect that could easily be heard on a drum sound. Wah wah was also tested, but was not as successful in providing a clearly audible effect.
The output of the snare mechanism and subtractive synthesis modules can be sent

to a variable delay line, the length of which is modulated by a sine wave, creating a flanger effect.

Sample Playback

Sample triggering is a classic mainstay of the trigger approach to electronic percussion. It can be very effective, is easily understood and has the potential for the user having complete control over the choice of sound.
Onset detection is carried out by the same method as for the subtracted synthesis model above. Sample playback is triggered at rates and directions that can be adjusted via the UI.

3.11.2 Mapping

Amplitude

Amplitude of vertical vibration of the batter head is used to control the peak output of the snare mechanism, this is almost a direct mapping, but a 1 ms attack time is applied to it to maintain a smooth output. The release time is adjusted via the UI allowing for interesting, potentially *unreal* effects.
A similar mapping is used for the subtractive synthesis and sampler modules, but the amplitude of the detected peak is used instead of the direct signal. In the case of sample playback, the overall amplitude is set by the detected onset amplitude, but the amplitude envelope is dictated by the sample itself.

Spectral Brightness

The user defined release time is scaled by the spectral brightness of the detected onset reported by *bonk*∼ such that a brighter attack will result in a longer release time.

Topographical Mappings

The surface of the drum is divided into two expandable regions. (See Figure 3.10.). The output of the subtractive synthesis and sample playback modules can be assigned to either of these regions via the UI. The snare mechanism is restricted to the centre region.
Both regions can be adjusted in sensitivity such that the response appears to be more or less localised.

3.11.3 User Interface

The UI developed out of a need to adjust parameters during software development. Two potentiometers and three momentary push buttons were used in conjunction

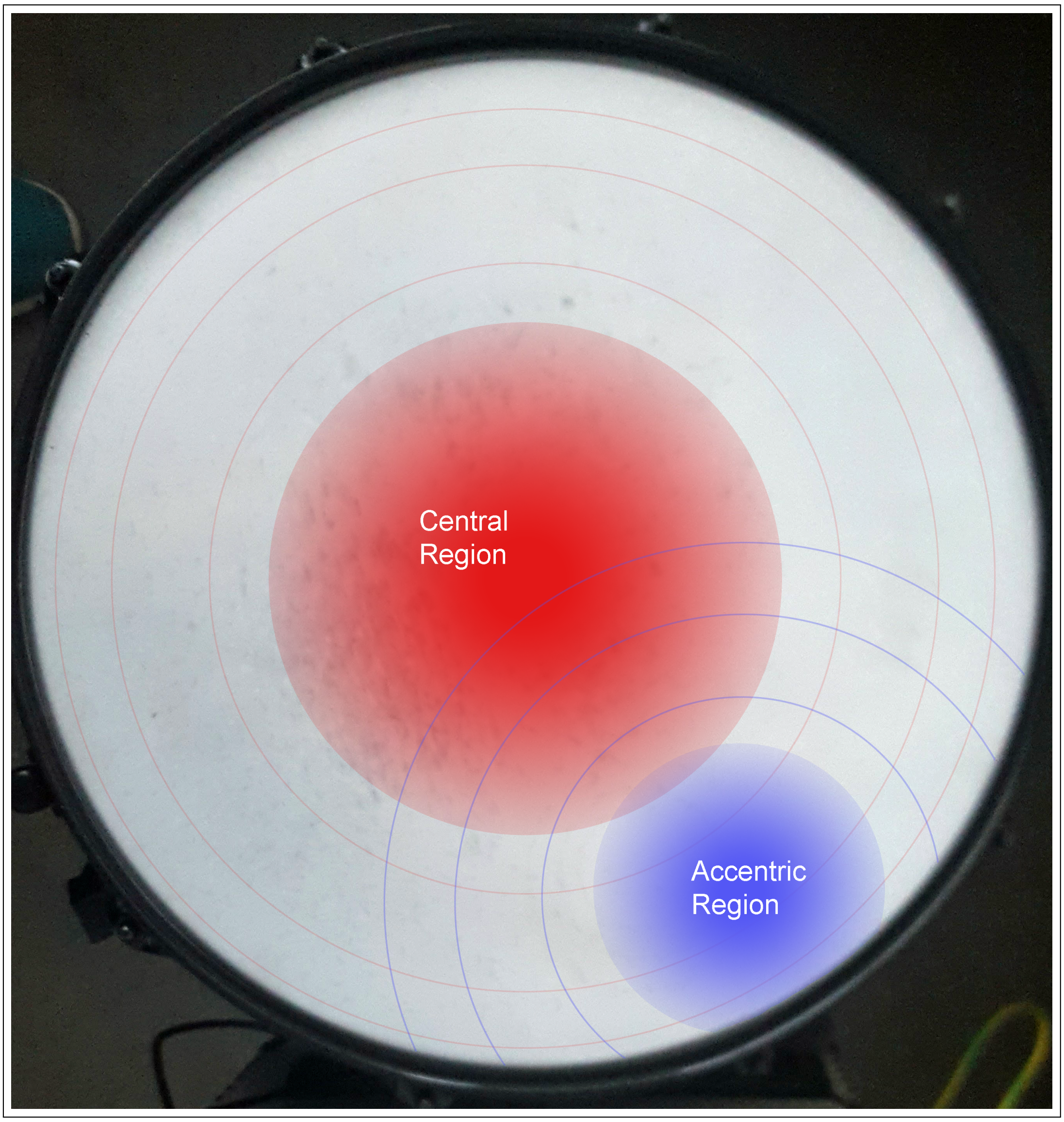

Figure 3.10: Topographical Mapping Regions

with data printed to the console of the browser to de-bug and find appropriate constants and pre-sets for variables. For evaluation an array of light emitting diodes (LED) was constructed to make the instrument appear more self contained, and generally make the interface more aesthetically pleasing, whilst giving the performer a physical representation of the user definable variables that are available beyond interaction with the drum itself. A picture of the UI can be seen in Figure 3.7

Chapter 4

Evaluation

4.1 Latency and Jitter

One design requirement was to keep latency as low as possible. This was addressed by using the Bela Cape and BeagleBone Black. The latency was measured as follows

4.1.1 Equipment

- Rode nt2a microphone
- M-Audio M-Track Plus MkII USB audio Interface
- Windows Voice Recorder
- Sonic Visualiser

4.1.2 Method

The microphone was situated 50 cm from DAD at an angle of 45^o to the plane of the batter head. The signals from the microphone and from the jack output of the Bela Cape were connected to separate inputs of the audio interface. DAD was then struck, centrally, with a drum stick twenty times in succession at intervals of approximately one second.
The resulting stereo audio file was then loaded into Sonic Visualiser, and the distances between onsets across channels measured individually. The mean average of the latencies was taken as the latency and Jitter as the maximum deviation from the mean

4.1.3 Results

Taking the latency of arrival of the acoustic signal at the microphone to be 1.47 ms, the latency of the DAD system using the snare mechanism only was 11.15 $\pm$ 1.2 ms, and the subtractive synthesiser module gave a result of 15.96 $\pm$ 6.3 ms. (See Table 4.1)
The difference in latencies for snare mechanism and subtractive synthesis patches is most likely due to the use of bonk$\sim$ and the print object used to send detected onset data to the rest of the patch. The latency for the sample patch was not calculated as this may have varied from sample to sample depending the amount of un-trimmed space at the start of each file and the selected playback speed.
These values, particularly for the subtractive synthesis patch, seem high. However, there will be a certain amount of temporal masking with the acoustic attack of the drum itself. It should also be noted that Aimi reported values of up to 15 ms of jitter going noticed by highly skilled percussionists, and values of up to 40 ms presenting no obstacle to their musicianship [2].

4.2 Frequency Response

The synthesis used in DAD was developed by audition and educated objective developer appraisal rather than through signal analysis alone. During expert evaluation it was hypothesised by evaluators that the speaker used in DAD might not be capable of recreating the high frequencies of a snare mechanism. It was a known issue that the speaker was a mid range device, but in order to optimize and analyse the performance of the speaker the following test was carried out.

4.2.1 Equipment

- Rode nt2a microphone
- M-Audio M-Track Plus MkII USB audio Interface
- HOLMImpulse version: 1.4.2.0

4.2.2 Method

The microphone was situated 50 cm from DAD at an angle of 45^o to the plane of the batter head in the centre of a near anechoic room . This position was chosen to approximate the auditioning angle and position of the player. A six second chirp signal was fed into the upward facing speaker and then the audio exciters on the resonant head, and the microphone signals analysed to produce frequency response plots. See Figure 4.1

Table 4.1: Latencies measured using Sonic Visualiser

Snare Drum Latencies	Synth Latencies
0.00954649	0.0141497
0.00977324	0.014898
0.010068	0.0163946
0.00965986	0.0153061
0.00968254	0.0137415
0.00952381	0.0148299
0.00977324	0.015034
0.01	0.00823129
0.00956916	0.015102
0.00941043	0.0153741
0.0099093	0.0158503
0.00984127	0.0126531
0.00941043	0.0163946
0.00970522	0.014898
0.00965986	0.00986395
0.00847846	0.0142857
0.00968254	0.0162585
0.0103401	0.0154422
0.00993197	0.015034
0.009654	0.0159864
Latencies	
9.680996	**14.486397**
Jitter	
1.202536	**6.255107**

4.2.3 Results

Both frequency responses show a peak around 800 Hz which is most probably caused by the tuning and resonances of the drum. The audio exciters show a flatter response than the speaker. The loudspeaker was chosen for it's availability and power handling. The roll off in response from around 2.5 KHz should not be a surprise as it is a midrange speaker, but it shows that it may not have been an optimal choice. This is discussed further in chapter 5.

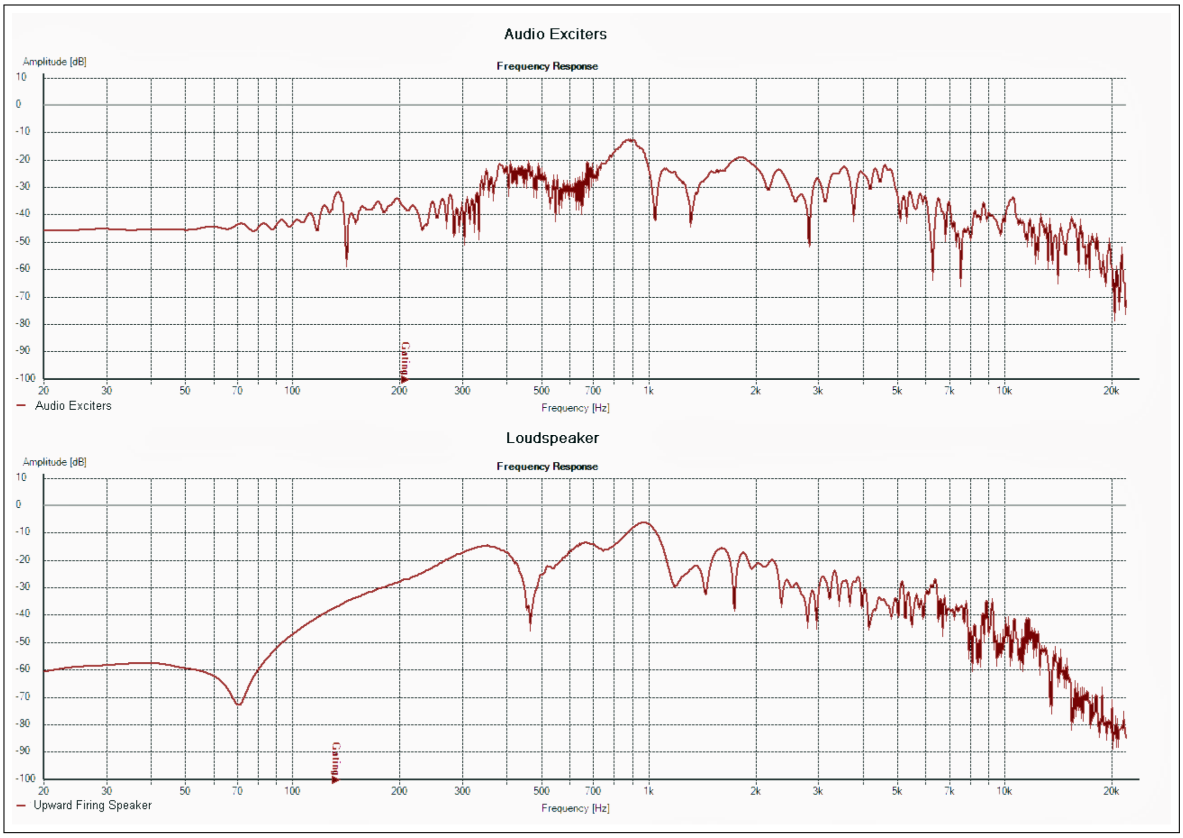

Figure 4.1: Frequency Responses of DAD Audio Transducer Systems

4.3 Expert Evaluation

A series of five sessions were set up over five days to evaluate various aspects of DAD using expert performers and co-performers. Each test was designed to evaluate specific aspects of DAD, and to simultaneously provoke feedback that would test all success criteria.

4.3.1 The participants

Seven male musicians took part in the expert evaluation.
Five were drummers aged between thirty-eight and fifty three, with an average age of forty-five. All had played electronic percussion before. There was also a guitarist / pianist aged thirty-eight and a vibraphonist aged thirty-nine. The author also took part as a co-performer on bass ukulele and bass guitar.
All seven musicians taking part play to a professional standard with the exception of one drummer, who describes himself as a keen amateur, and plays caixa rather than drum-kit.

	Age	Years Playing	Playing Standard	Prefered Genre	Drum for Comparison
Mikkel U	39	27	Semi Professional	Jazz	Brass 14″ x 6,5″ Steel and gut strings
James W	46	7	Keen Amateur	Funk, Samba	12x08″ Caixa, Aluminium
Mikkel F	53	37	Professional	Jazz	Tama Cherry Wood 12"x 5" Piccolo
Danni J	35	24	Professional	Rock and Pop	Ludwig Steel Supraphonic 14" x 5.5"
Tomas M	50	40	Professional	Jazz	Sonor Hilite, Maple 14" x 5.5" (This was not the musician's own drum)

Table 4.2: Drummers taking part in Evaluation

Their musical education and genre of main activity varied. The vibraphonist played jazz, and the caixa player played funk and samba. The remaining musicians had extensive experience in multiple genres. Detailed information can be seen in Table 4.2.

4.3.2 Method

The first three sessions were carried out in a near anechoic room on the Aalborg University Copenhagen campus. These were all solo sessions that took around two hours to complete. DAD was initialised prior to the participant entering the room. A set of drumsticks, beaters and brushes were provided so that in the event the participant had not brought their own, or only brought sticks, these interactions would be available to them. A specially cut rubber muting mat was also provided so that they could dampen the battered head if they so wished.

The last two sessions were each held in different rehearsal rooms in Copenhagen. These were group sessions consisting of one drummer, one invited co-performer and the author. The principle aims of these sessions were to test for the success criteria that DAD could function as a snare drum in a group situation and to explore the perspective of the co-performer.

A Google form was used to collect participant responses and guide the process of evaluation. This form failed due to wi-fi connectivity issues during the first group session, resulting in a loss of data. Paper forms were used in the final session as a precaution against further issues of this nature.

The author was observing behaviour during all the sessions, and was able to review video footage looking for any data that appeared relevant to evaluation.

The following tests were carried out in the order described below:

Collection of Background Data

Various demographic data and usage permissions were gathered.

Preperation

Each drummer had been asked to bring their own drum and were asked to play it for a few minutes, first with the its snare mechanism engaged, then disengaged. This was done to remind the drummer of the sound and behaviour of their own drum, so that it could be used as a reference point. This also provided the drummer an opportunity to adjust the snare stand to suit their preferred playing position.

Test 1 - Perception

The aim of this test was to determine…

- …how natural sounding DAD was with various pre-set subtractive synthesis sounds being triggered
- …how instinctive the topographical mappings were. (See subsection 3.11.2.).
- …if the injection of synthesised tones into the drum made the interaction less clear

Each drummer was asked to play DAD in each of six states. One state was without any effect and the rest were with five different pre-sets chosen to present a variety of subtractive synthesis sounds. None of the sounds were considered to be incongruous by the author. All were presented with the same output levels for each musician. The pre-sets were presented in the same cyclical order, (A, B, C, D , E, F), but each musician started on a different pre-set. See Table 4.3 and Table 4.4. When the drummer felt comfortable, they rated the drum setting, on a seven point Likert scale for each of the criteria listed below:

- Resonance *
- Richness *
- Clarity *
- Naturalness
- Engagement
- Balance *

- Dynamic Control
- Playability *
- General Preference

The descriptors marked with an asterisk (*) came from a study into how musicians evaluate violins [43]. As mentioned in section 2.8, this approach has been used in other studies. Naturalness was used as an indication of how *realistic* the effect of injecting the synthesised sound into the drum was. Engagement was chosen because, unless an instrument is engaging it will not hold the musician's interest. Dynamic control was used to test the reliability of the mapping and general preference was used to give an overall impression of whether the drummer was more inclined to the acoustic drum.

The author observed the drummer during this process, made notes of any questions that were asked and changed pre-sets when appropriate.

Table 4.3: Synthesizer pre-sets for perception test

Pre-set	Topographical Mapping	Filter 1	Filter 2	Filter 3	Sweep
A	Centre Focussed	202.4	339	475.6	Negligable
B	Entire Drum	206.2	363.9	521.7	Slow
C	Centre Focussed	170.6	279.8	389	Very Slow
D	Acentric Focussed	177.4	290.9	513.7	Very Slow
E	Acentric Focussed	177.4	298	418.7	Slow
F	No Synthesis				

Table 4.4: Pre-set Presentation Order for perception tests

Participant	Pre-set order					
Mikkel U	A	B	C	D	E	F
James W	B	C	D	E	F	A
Mikkel F	C	D	E	F	A	B
Danni J	D	E	F	A	B	C
Thomas M	E	F	A	B	C	D

Introduction of Design concepts

Solo sessions: As in the evaluation of an a earlier project [50], various design and evaluation concepts were introduced and discussed (see list below) in order to focus conversation towards frameworks and concepts present in the sound and music computing community.

Group sessions: To save time, during the group sessions, theses concepts were presented as a print-out to help the participants think of comments. Concepts presented were:

- Experienced freedom and possibilities
- Perceived control and comfort
- Perceived stability, sound quality and aesthetics
- Learnability
- Explorability
- Feature controllability
- Overall experience
- Timing controlability
- Categorisation
  - instrument like
  - extended instrument
  - instrument inspired
  - alternative instrument

Test 2 - The Snare Mechanism

This test was designed to appraise how effectively the snare mechanism synthesis was designed and implemented.

Solo sessions: The UI was introduced, and section by section, the control, effect and concepts of the snare mechanism module were introduced. At each stage the participant was encouraged to explore the possibilities that the section afforded them, and to generally play the drum, with whatever technique they wished. After having played with all the available settings for this module the participant was asked to rate how easy or difficult, or good or bad the experience was according to the series of parameters listed below. A five point Likert scale was used. They were also encouraged to comment freely on the experience.

- Mentally

- Physically
- Timing
- Frustration
- Engagement

These test parameters are derived from the NASA TLX tests. This has been used to test playability of an instrument other studies [52].

Group sessions: A printed A4 sheet explaining the controllable parameters of the snare mechanism was given to the drummer and co-performer. The drummer was then asked to choose one of four pre-sets that had been prepared earlier, and told that they could edit them, with the assistance of the author if they so wished. Once they were content with the settings, the group played a piece of music and discussed the experience. The drummers then rated their experience as in the solo sessions.

Test 3 - Subtractive Synthesis Module

The same procedure as in test 2 was then carried out for the synthesiser module.

Test 4 - Effects and Sample Module

The effects and sampler modules were then presented and rated according to the same criteria as in tests 2 and 3 after they had all been thoroughly explored by the participant.

Test 5 - Solo recording (solos sessions only)

The participant was then asked to adjust the settings of DAD according to their taste, and invited to perform a short solo, which was video recorded. This ensured that they had experienced the drum in performance and supplied material for documentation purposes. This also indicated each performers preferences in terms of which digital sounds the evaluating performers found most musically useful. This material was also used in a series of informal open interviews intended to explore audience reaction to DAD. People were asked to view various video clips and comment openly on what they witnessed.

Test 6 - Comparison test

The participant was asked to compare DAD to their own snare and state which of the two they felt was best according to the criteria listed below.

- Experienced freedom and possibilities
- Perceived control and comfort
- Perceived stability, sound quality and aesthetics
- Learnability
- Explorability
- Feature controllability
- Overall experience

System Usability Scale

An adapted form of the SUS test was then taken by the drummer participants in order to determine if the concepts of control and interaction were understood and practically implemented. This test was the same variant of SUS that had been developed for a previous project [50]. The SUS questions can be seen in the expert evaluation form questions in Appendix C.

Basic Tasks and Open Discussion

The following questions were asked of the drummers.

1. Can you play at a steady tempo?
2. Can you incorporate a localised sound into a pattern?
3. Can you play freely (sound effects)
4. Is it possible to quickly change timbre?
5. Are you able to make musical use of variation in sound?
6. Are you able to play dynamically?
7. Are you able to use a variety of techniques and still make use of DAD's features?

Time was then allowed for a general discussion about the session.

4.3.3 Results

Test 1 - perception

Most drummers, and all co-performers found it very difficult to detect any difference between settings. Synthesis signals were deliberately low in order to determine how influenced they were by small changes in the sound of the drum. It was really only the drummers who thoroughly explored the drum that were able to determine the mappings and explore them.
It was apparent that the topographic region markings were not very clear. Only one drummer saw them and this was because he had placed a lamp above DAD to help with video recording. With only four drummers having taken the test there is little point in extensive statistical analysis, but a clear trend for favouring the acoustic instruments without synthesis was visible for clarity and general preference (See Figure 4.2).
Judging from comments made by two drummers and both co-performers, they could not hear that there was any difference between pre-sets.
The other three drummers (the more experienced drummers), were able to quite quickly determined that certain areas of the drum produced different sounds. One of them even spontaneously started a short solo based on this discovery.

Test 2 - Snare Mechanism

None of the drummers were particularly happy with the snare mechanism synthesis. They all felt that it was missing some presence.
All drummers were content with the mapping, (See subsection 3.11.2), felt that it reacted quickly enough and felt that the sawtooth amplitude modulation gave a reasonable impression of a loose set of snare wires.
Opinion was split about the artistic value of the snare mechanism synthesis. Some drummers felt that the more extreme, *unrealistic* sounds were great fun, others did not think that they could use them.
A method of controlling the synthesis parameters in a fashion more suitable to performance was suggested, with one drummer suggesting some form of embodied interaction. *i.e.* not via knobs and switches.
All but one drummer suggested that their own snare sound was very personal, and that they would likely be unhappy unless they could match it very closely.
Both co-performers felt that the snare mechanism sounded realistic in group performance. One co-performer observed that one of the pre-sets sounded almost exactly like an acoustic snare can sound when a drummer places a small splash symbol on the surface of the drum, indicating that at least for him there was artistic value in a stochastic synthesis that does not sound exactly like a snare mechanism.
There was a distinct correlation between verbal criticism of the snare mechanism synthesis and their affinity with their own drum. The least criticism came from

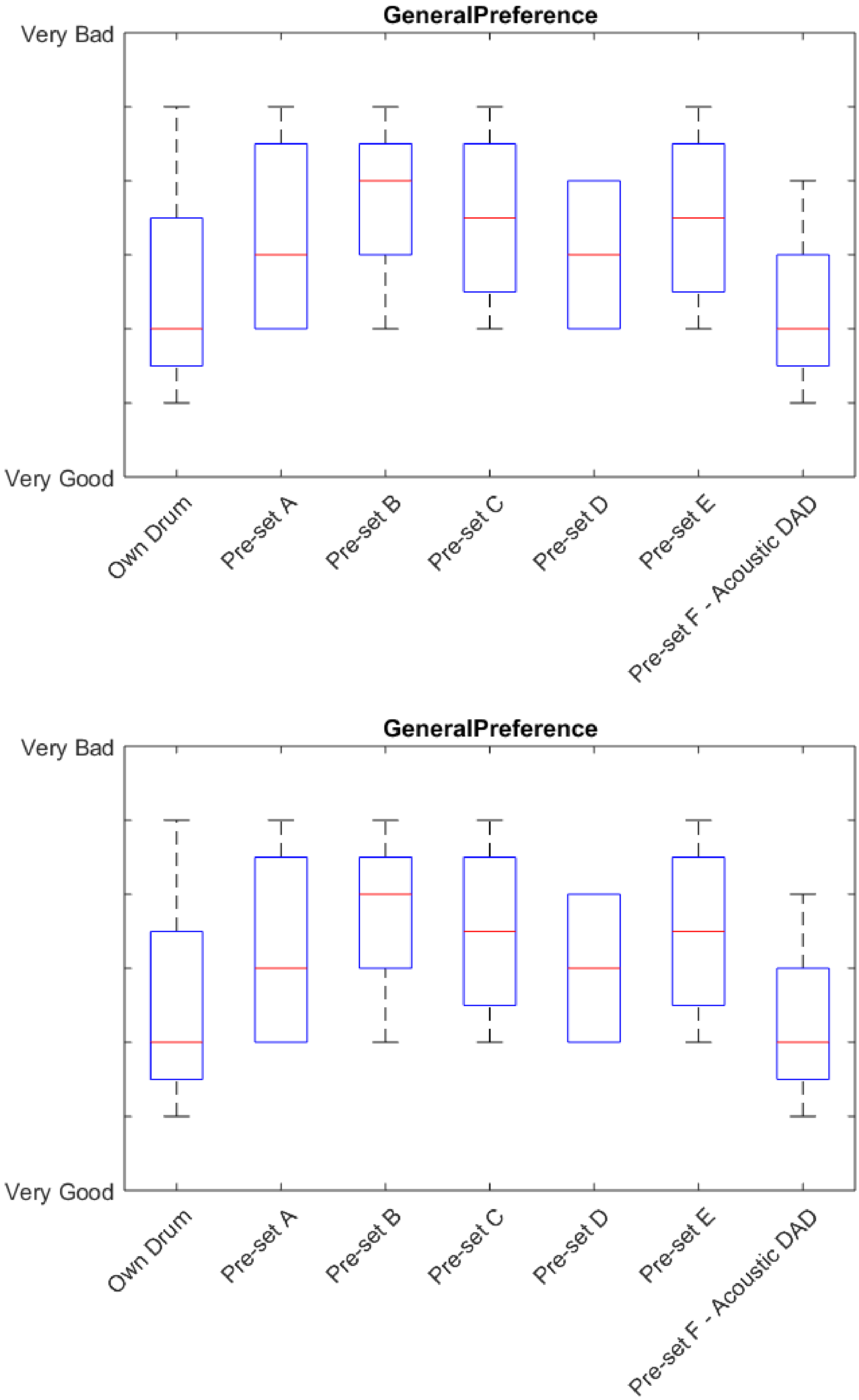

Figure 4.2: Perception test results for clarity and General Preference

Thomas M who had borrowed a high quality snare that was in the rehearsal room. The most criticism came from James W, who played a Caixa, a relatively cheap instrument, but one where the snare wires are on top of the drum and determine the precise sound and playing style with which it should be used. Harsh criticism also came from Danni J who was able to give very precise information about the construction and date of manufacture of his snare drum, almost without prompting. The playability scores for the snare mechanism tended to be higher (less playable) than all the other modules (See Figure 4.3.). This reflects the frustration the drummers were having in finding a sound they were happy with.

Test 3 - Subtractive Synthesis Module

The drummers accepted the sounds produced by the synthesis module without criticism, all were inspired to change their playing styles. All, including the co-performers, noted that the sound somewhat dictated how they played.
The introduction of the acentric topographical mappings resulted in all the drummers commenting that they changed their perspective in evaluating DAD. They shifted paradigm such that they no longer considered it a snare drum. No two drummers cited the same instrument, but a cajon, a steel drum and a hang drum were all mentioned. One stated that he felt it was more suited to percussionists such as Trilok Gurtu or Airto Moreira, who have a set-up comprised of parts of a drum kit and several items of percussion.
The playability ratings show that most drummers found DAD easier to play whilst the synthesis module was active than with the snare mechanism. This fits with their comments, but it could also indicate a learning curve as they had begun to understand more of the concept behind DAD. (See Figure 4.3)

Test 4 - Effects and Sample Module

Overall the effects module and sample triggering were received more favourably than the previous two modules. This could be a learning curve effect. Personal preference varied greatly within this module. Some found the ping pong delay very difficult and confusing, whilst others found it one of the most entertaining aspects of DAD.

Test 5 - Solo recordings

All drummers chose very different settings and played very different solos.
When playing the video clips back to a variety of people, including some people taking part in the expert evaluations, a range of observations were made:

- Some subjects reacted purely to the performance, discussing the musical performance in terms of how it affected them emotionally. Their reaction

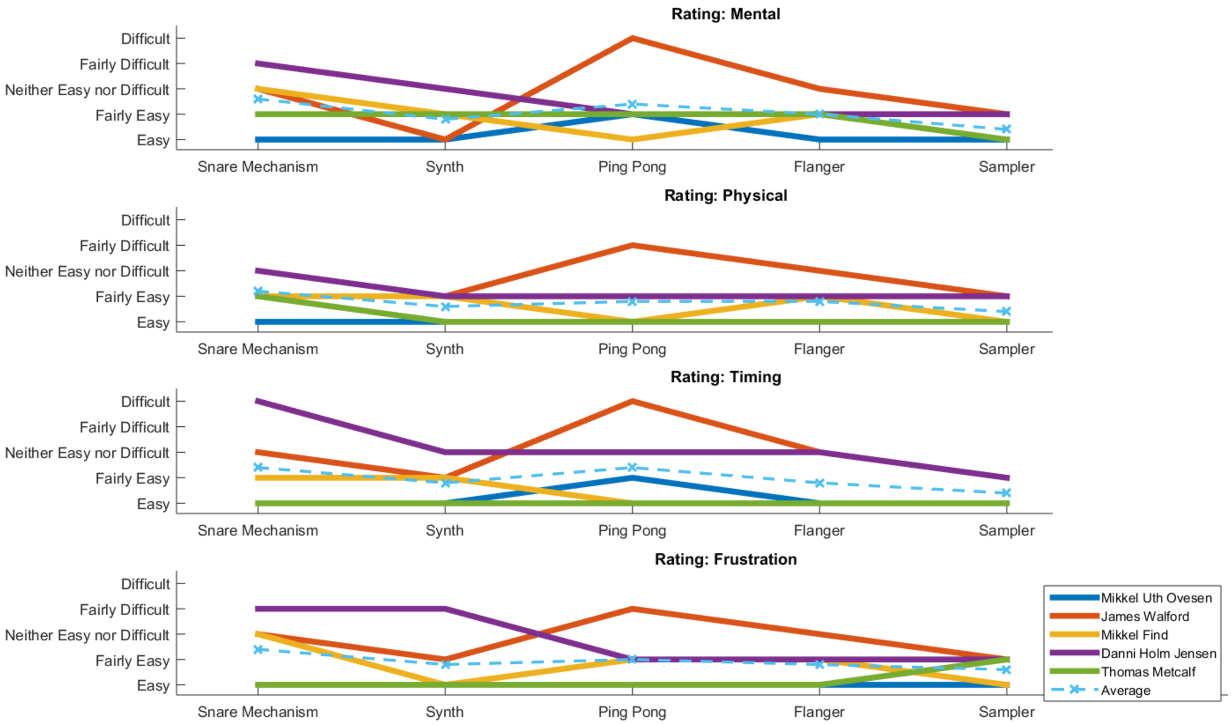

Figure 4.3: Playbility scores for all drummers

suggested they were unconcerned with fitting the instrument itself into any model of interaction and were more concerned with the music

- Some subjects responded by playing video clips that they felt were related, or talking about a particular musician or kind of music where they thought DAD would be appropriate. This suggested that they categorised the performance by genre rather than by musical technique. These subjects generally had an interest in electronic music.

- Most subjects wanted to know how much of the sound they could hear was under the direct control of the musician, and how that control was established. This suggests that their model is similar to the users model in that it was concerned with understanding the physical interaction.

- A small number of subjects wanted to know the capabilities of the instrument. *What sounds can it make? Could it be used for a particular role or purpose within a group?* These subjects were exclusively musicians.

Test 6 - Comparison Test

Results for the comparison tests can be seen in Table 4.5 Almost without exception all drummers felt that DAD outperformed their own snare with regard to *Freedom and possibilities*, Danni felt restricted by DAD's response in this respect. His comments suggest that he was trying to reconcile his internal model of a snare drum with DAD's response. This restricted his sense of freedom on the new instrument. All drummers indicated that DAD was more explorable than their own drum.
In every other respect DAD came second to a traditional instrument.

Observations and Feedback

The consensus of opinion was that DAD provides new expressive possibilities, and does so in a way that allows for full use of the acoustic drummer's gesture vocabulary. It does not in anyway degrade the acoustic qualities of the snare drum with one exception; The snare mechanism synthesis was not satisfactory, and the sonic characteristics of the acoustic snare mechanism are necessary for it to be used as a snare drum replacement. Several drummers felt it could function as a very interesting second snare drum. Detailed observations made during the evaluation sessions can be seen in Table A.1.

Several drummers found that playing DAD with hands or beaters was more satisfying than with drum sticks. A number of explanations were put forward. Danni believed there was an incongruity of expectation when the acoustic attack of the snare was two loud in comparison to the synthesised sound. Mikkel Find's

	Mikkel U	**Mikkel F**	**Thomas M**	**Danni J**	**James W**
Freedom and Possibilities	DAD	DAD	DAD	Own Drum	DAD
Perceived Control and Comfort	Own Drum	Own Drum	Own Drum	Own Drum	Own Drum
Stability Sound Quality and Aesthetics	Own Drum	Own Drum	Own Drum	Own Drum	Own Drum
Learnability	Own Drum	Own Drum	Own Drum	Own Drum	Own Drum
Explorability	DAD	DAD	DAD	DAD	DAD
Controllability	Own Drum	Own Drum	Own Drum	Own Drum	Own Drum
Overall Experience	Own Drum	Own Drum	Own Drum	Own Drum	Own Drum

Table 4.5: Comparison Tests for DAD

explanation was more instinctive, he could hear the response better when playing with his hands. He was able to obtain a stark contrast between the acoustic and synthetic sounds using this technique.

A number of drummers, including some who did not officially take part in the evaluation, were able to obtain an interesting effect that answered, at least partially, one of the suggestions obtained during initial interviews (section 3.3). When playing with brushes simple brushing gestures give a purely acoustic response, where as a hit with a brush produces a synthetic output. This has the result of amplifying accents when using brushes.

Several drummers were able to use the muting as a method of contrasting the synthetic output with the acoustic output, effectively mixing the two.

Thomas M commented that there was some inconsistency in the triggering of samples from the acentric sensor. Reviewing video footage shows this is also apparent when using the subtractive synthesis module. Whether this is a programming, computer hardware or sensor component error should be investigated. During development one sensor was damaged through normal use of the drum. Although the drum head was tuned too low at the time of the damage being incurred, potential for unwanted impact on a sensor so close to the batter head should not be ignored.

The aspect of having more gain on the synthetic output can be used to great expressive effect, but it can be difficult to control. This was taken into consideration in development by adjusting a high pass filter before the onset detection and amplitude mapping stages. However, different drummers use different ranges of dynamics and this was not successfully accounted for.

Reviewing the video it was apparent that integrating DAD into a drum kit was no easy task. It was not just a matter of rhythmic control, but dynamically balancing sounds with the rest of the drum set.
Both drummers taking part in the group sessions found that once they had got used to the concept of DAD they could easily play with the group.
Danni J noted that playing with more synth sounds from the other musicians might have been interesting as that would have better matched the sounds DAD was producing.
No drummers voluntarily commented on the collocation aspect of the design. When prompted they all said that it felt very natural, and they appreciated it when it was pointed out to them. Only Thomas M said that the location of the sound did not matter to him, with the caveat that it would help from the point of view of being aware of the mix between acoustic and synthetic sounds.
One of the co-performers noted that due to the topographical mappings, hand percussion rhythm patterns became completely transformed when played on DAD. He enjoyed this very much.
Several drummers believed that DAD would be ideal as a stand alone instrument for *non-traditional* gigs, such as accompanying dance or experimental theatre.

System Usability Scale

SUS scores (Table 4.6) were low for DAD compared to bEADS, where the same test had been used [50]. Frustration with the perception tests and dissatisfaction with the quality of the snare drum may have left a negative impression on the participants, but low SUS scores are not necessarily indicative of a poorly designed instrument. All the drummers, and one of the co-performers suggested that DAD did not function as a snare drum. Adjustment to a new internal performer model of the instrument combined with a confusing UI are the most likely causes of this low score.

Average	**Standard Deviation**
43	3.26

Table 4.6: SUS scores for DAD

Additional Comments and Observations

During development other drummers and observers tried DAD in various stages of development and gave their opinion. One drummer, with experience of both traditional and electronic percussion, noted that the collocation of sound meant that

DAD would sound the same wherever he was playing and that this was a significant bonus. He also liked that DAD was a new instrument that he could explore, and find new sonic possibilities without having to learn new techniques. He found the best balance between acoustic and electronic paradigms was facilitated when he played with brushes, as noted by other drummers during evaluation (above).

Basic Tasks

Overall DAD performed well in this test, however, the musicians with the most professional experience were more critical. This could indicate that they are more sensitive to the limitations of an instrument due to their higher level of skill and control. The most critical musician was Thomas M. He tested DAD in one of the group sessions and this may have had an effect on his judgement as he was viewing DAD as part of a larger instrument, where it should play a more specific role within a drum kit. Limitations in the quality of the snare synthesis, and the challenge of applying new techniques, however subtle, to a specific component of the entire kit, may have tipped his opinion. The results can be seen in Table 4.7.

	Mikkel U	Mikkel F	Thomas M	Danni J	James W
Can you play with a steady tempo?	yes	yes	yes	yes	yes
Can you incorporate a localised sound into a pattern?	yes	yes	yes	yes	yes
Can you play freely?	yes	yes	no	yes	yes
Is it possible to quickly change timbre?	yes	no	no	yes	yes
Are you able to make musical use of variation in sound?	yes	yes	yes	yes	yes
Are you able to play dynamically?	yes	yes	yes	yes	yes
Are you able to use a good variety of techniques and still make use of DAD's features?	yes	yes	no	yes	yes

Table 4.7: Basic Tasks - Self Evaluation

Chapter 5

Discussion

5.1 Evaluation Method

As O'Modhrain points out, the most important opinion when it comes to judging a musical instrument has to be that of the performer [34]. For this reason the evaluation in this report, and the development process, has set great focus on the opinion and insight of experienced musicians.

One of the difficulties of this approach is that musicians are human beings, and as such they have different needs, aesthetic preferences and playing styles. They also have different levels of ability.
A talented professional percussionist will be able pick up almost any object and make music with it. One has to be wary then, as the observer, to judge the instrument and not the performance. However, it is the author's view that such talented musicians are in the best position to search out the expressive limits of a new instrumental design, especially one based on an existing traditional paradigm. In order to guard against the possibility of studying musicianship rather than testing DAD's potential to meet the success criteria set out in section 2.10, a range of drummers with different specialisations were invited to take part, including one keen amateur. The dedicated novice musician is in a position to test entry level expressive possibilities in a way that neither a complete beginner, nor arguably a professional musician would be able to.

Five evaluation sessions were conducted. Three sessions with only a drummer, and two in group situations where DAD was set within an entire drum-kit. The assimilation of DAD into an entire kit had a profound effect on the formulation of performer models. Both group session drummers were able to adjust, but they were not given the same freedom to explore DAD as the drummers involved in the solo sessions. This may have affected the quantitative data derived from these sessions. Given the opportunity to re-evaluate an updated version of DAD, participating drummers should take part in both types of session.

Using some of the descriptors taken from Saitis, Giodarno, Fritz and Scavone's study of violin evaluation [43] and transferring that vocabulary to this study (section 4.3) was based on it's success in other research [50, 22]. It's effectiveness in this context has to be questioned simply because a significant number of participants required classification over the meanings of certain words. This could be due to Danish being the first language of most people taking part (in Saitis, Giodarno, Fritz and Scavone's study English and French were the primary languages), or it could be that some of these descriptors are actually specific to genre, social group, or indeed instrument class.

Any analysis of the quantitative data obtained in this study has been viewed as limited by the relatively low numbers of participants. Time restraints and the busy schedule of professional musicians dictated the number of participants that could be included. The reported results have been limited to those where trends were clearly discernible.

The presence of what may be a learning curve can be seen in Figure 4.3. This may have been exaggerated by a general dissatisfaction with the quality of the snare mechanism synthesis.

An attempt to gain the perspective of the co-performer was hampered by a combination of data collection failure and an unforeseen, but entirely natural concern of the co-performer, that they were being asked to judge the drummer's performance rather than the behaviour of DAD. For example, the one co-performer for whom data collection did not fail had a propensity for marking the dynamic control as very good for all tests and was overheard informing the drummer that he had done well. In a future design the tests should be carefully worded to try and avoid this.

5.2 Implications for Models and Frameworks

In subsection 2.7.1 three perspectives of system representation are listed. The system, the user and the design model. O'Modrhain mentions these in her background before outlining the stakeholders in her framework for DMI evaluation [34]. She identifies the audience, the performer and the designer as the main stakeholders. In this paper a fourth potential stakeholder, that of the co-performer, has been proposed.

It was assumed that the co-performer's perspective would be somewhere in between the audience and performers. More informed than the audience, but from an observers point of view. This proved not to be the case with the two co-performers used in this study. They were unconcerned with the mechanics behind the interaction with DAD (at least while performing) and were focused on the sound and musical role of the instrument. This is distinct from the performers perspective as it contains no element of control. It does bear some similarity to some of the audience reactions noted in subsection 4.3.3.

The audience reactions in this study suggest a number of different perspectives that can be adopted. It is likely that they depend largely on the audiences prior understanding of music. Those that play an instrument are likely to want to understand how the instrument is controlled, and this becomes important to their enjoyment of the music.

As noted in section 5.1 there was some indication of a learning curve, but there was a marked change in attitude from all drummers involved in the evaluation when the presence of topographical mappings became apparent. They all made references to instruments other than the snare drum, and their playing became more fluid. This shows how important an alignment between a performers model and the behaviour of the instrument can be.

Context was also very important for the performer. Absorbing DAD into a drum kit apparently changes the role of the instrument, restricting the extent to which the drummer can explore it. When using DAD as a solo instrument participants wanted more outrages sounds, they were not interested in subtlety. This observation was made by Aimi with regard to at least one of the experts he worked with [2]. However, in group situations these ear catching sounds needed and demanded space, a more discreet set of sounds was required.
It was also noted that the sounds themselves could draw the musician into exploration. Particular sounds were indicative of particular genres, and this helped the performer define their internal model of DAD.

Giving the computer limited control with the ping pong delay was greeted with mixed reaction, (this fits with observations made by Maki-Patola, Hämäläinen and Kanerva with regard to their Augmented Djembe Drum section 2.5). It appeared that the experience of the musician, and the musical context had an affect on how content the musician was. Unsurprisingly, the more experienced a drummer was, the more confident they were in allowing the computer to edge towards the role of co-performer whilst still being able to play expressively. In group situations this became more troublesome. This issue is similar to the problems associated with playing to a click track. Some drummers can do it, others cannot.

5.3 Design Implications and Future Development

The goal of the snare mechanism synthesis was to provide an adjustable pseudo-snare audio output. It was intended to represent possibilities rather than recreate a snare mechanism. This approach apparently underestimated the requirements of the musicians taking part in the evaluation. The specific sound of a snare mechanism was apparently a necessary component in their internal performer model (subsection 2.7.1) to such an extent that they could not happily interact with DAD as a replacement snare drum. Any future version of DAD should take steps to address this.

Realistic synthesis of drums is a significant technical challenge and one that is beyond the goals of this study. A simple and direct solution would be to remove the audio exciters from the resonant head and replace the snare mechanism, any snare mechanism synthesis would then augment the acoustic signal.

The use of a more traditional synthesis approach such as wave table synthesis might also provide better results.

Another, more general improvement, that may also improve the synthetic snare performance would be to use a full range speaker or set of speakers, and a higher quality of amp.

The audio exciters were immediately available and provided a method of producing a broad range of frequencies. They also, in combination with the loudspeaker, provided alternating directional output for the ping-pong delay. This effect was found to be pleasing during development, but was not commented on by any of the evaluating musicians. The audio exciters themselves do not provide anything in this context that could not be achieved with an appropriately designed speaker array.

The SUS score for DAD was low, at 43, this, according to a study that mapped an adjective rating to SUS scores, is somewhere between *poor* and *good* [3]. SUS tests were developed for determining the effectiveness of interaction design for less abstract systems than musical instruments. It is more suited to appraising web designs, or computer operating systems. It has been adapted for use for new musical instruments, but lacks a systematic method of interpreting results. The same variant of SUS test was used by the author in evaluating another prototype, bEADS, a digital shaker. bEADS scored between 60 and 92, but it was a far simpler instrument. It could be that the score of 42 for DAD is indicative of an instrument that requires more time to master. It cannot be denied that the user interface, and the need for instinctive control of parameters needs to be refined. It should also be noted that this low SUS score fits with analysis of Wavedrum's poor commercial performance in that some reviewers believe it was too complicated. See section 2.2.

During perception tests (test 1 subsection 4.3.2) there was a clear preference for the pristine acoustic sound of DAD rather than with any synthesis, and this was the case whether musicians could consciously hear a difference or not. It had been noticed during development that very short pitched bursts of sound could have the effect of making the drum sound as if it were tuned differently without there being an overtly synthetic sound. It was this effect that was the inspiration for the perception tests. An improved design of this experiment might include an attempt to determine the optimum duration of synthetic signal such that the drum sounds natural, but still appears to have changed pitch.

A number of drummers expressed the desire for a more sophisticated method for controlling parameters such as filter width or delay time. They wanted a method that was more immediate, musical and cognitively cheaper than adjusting knobs and switches. Given that a drummer is almost always using both hands and feet to play their instrument, and that they need to adjust their body to look at their fellow musicians, and use facial expressions to communicate with them, it is difficult to conceive what this method might be. The obvious solution is to further decompose the surface of the drum. The decay time of the snare could, for example, become longer the further the strike from the centre of the drum. This would require more sensors, or a different sensor method, and may ultimately restrict the performers sense of freedom.

Latency was higher than expected, especially for the subtractive synthesis patch, but this was likely masked by the acoustic output of the drum and falls well within the 15 ms and 40 ms thresholds noted by Aimi in a hybrid percussion system [2].

5.4 Success Criterion and Problem Statement Revisited

The final problem statement was:

> Design a hybrid, **D**igitally **A**ctive snare **Drum** (DAD), designed for acoustic drummers

Such a prototype has been designed, built and evaluated.
The success criterion were:

- Function as a parametric snare drum.
- Serve as a snare drum in a group playing situation.

- Provide expressive possibilities beyond that of an acoustic snare drum.
- The acoustic properties of the snare drum should be maintained.
- Appeal to the target demographic.

Function as a parametric snare drum
Implementing a parametric snare drum was partially successful. Whilst the snare mechanism was not convincingly realistic, a range of sounds were available that were variations on the snare mechanism theme.

Serve as a snare drum in a group playing situation
In group settings DAD functioned as a snare drum only from the point of view of the co-performer. The level of synthesis precision that drummers in this evaluation required before being able to happily use DAD as a snare drum was underestimated. Co-performers could hear the difference, but felt that DAD functioned as a snare drum.

Provide expressive possibilities beyond that of an acoustic snare drum
DAD definitely provided expressive possibilities beyond that of an acoustic snare drum. All the evaluating drummers found the expressive range available to them entertaining and captivating. This can clearly be seen in results from the comparison test in subsection 4.3.3. This applied to the new sounds coming from the drum *and* the way that existing techniques such as muting and using brushes could give novel results.

The acoustic properties of the snare drum should be maintained
With the exception of the removal of the snare mechanism, the acoustic sound of the snare drum is unaltered.

Appeal to the target demographic
All the drummers who took part in the evaluation were interested in the prototype. It should be noted that whilst DAD does appeal to the target demographic, their view of the instrument was almost universally that it should be considered a second snare drum. In such a role four out of the five drummers said they would definitely consider using it.

Chapter 6

Conclusion

A prototype of an active hybrid snare drum has been built with the aim of providing musicians who prefer to use acoustic instruments some of the advantages of electronic percussion. Particular focus was placed upon providing an impression of the variety of sounds and effects that can be accessed through digital means whilst maintaining the quality of interaction and sense of self containment associated with acoustic instruments.

The prototype was tested by five drummers and two co-performers in solo and group performance sessions. Suggestions for improvement and verification of design concepts were obtained. This evaluation process builds upon an evaluation carried out by the author in a previous project [50], and represents a step towards the development of an evaluation and research protocol.

The current implementation points to an instrument that is more suited to use as a second snare drum, or as a snare drum inspired new musical instrument for solo use (not as part of a drum kit). In order for it to be considered as a replacement snare drum the snare mechanism synthesis would have to be significantly improved, or a genuine physical snare mechanism should be installed.

SUS results indicate that the UI should be simplified. The amount of variables should also be kept to a minimum.

The author believes that DAD represents a model for an instrument that could provide a very useful tool for acoustic musicians. Such an instrument would allow the exploration of a new sonic landscape. The skills and gestures built up over years of study could take on new meaning, or be returned to their original context at the flick of a switch. The current prototype needs significant improvement both in terms of synthesis and in the integration of controls before this can be realised.

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Appendix A

Expert Evaluation Notes

Table A.1: Open feedback from Expert Evaluation

Test Design
Mikkel Uth Although Mikkel is fluent in English, he sought clarification over some of the word definitions. Resonance required some explanation
James Walford James also had trouble interpreting the meaning of the word resonant in this context. English is his first language. This may indicate a problem with the test design, or it could be because he plays Caixa, which is designed to have very little resonance.
Mikkel Find Had some trouble understanding the word resonance in this context
Danni Jenssen Google forms failed to open on one machine, resulting in two participants completing forms on the same computer. This slowed testing down and led to confusion Danni needed clarification on the term *Engagement*
Troels Brandt

Was unsure of the definition of richness

Thomas Metcalf

The snare used as a refence point in this test had a small damper permanently attached to it's batter head

One of the audio exciters had come loose and was making a just audible rattling noise

Jakob Svensson

Expressed some concern about the perception test questions

Extra feedback from perception tests

Mikkel Uth

Mikkel found it difficult to discern whether there was any synthesised sound present with many of the pre-sets, and also was not sure if there was a difference between each test, however, when the dry sound of the drum was tested he immediately commented that it was easier to control and predict response, but that it was not as much fun to play with.

Even when prompted to explore the entire area of the drum, he did not find the acentric sensor.

Failing to find the acentric sensor led Mikkel to believe that there was a velocity threshold that had to be overcome in order to trigger a synthetic sound.

James Walford

James found it difficult to hear the difference between the clean drum and the drum with synthetic sounds.

He did not explore the full area of the drum skin, even when encouraged

Mikkel Find

Mikkel could clearly hear the difference between pre-sets in the perception test, he expressed a preference for setting D

Danni Jenssen

Noticed a difference between sounds from pre-set A, it raised a smile

Troels Brandt

Troels stated that control was more about the drummer than the drum

Troels could not hear that there was a synthetic sound during the perception tests

Thought he could hear the band rehearsing next door, this was actually the synthesiser module

Clearly had a listeners model of DAD which strongly separated the digital and acoustic sounds and interactions

Thomas Metcalf

Thomas heard the synthesiser from the first moment

Jakob Svensson

Could hear the rattling from the drum, but not the synthesiser, not until B

Jakob liked the synth once he heard it

Snare Mechanism

Mikkel Uth

Mikkel enjoyed the snare mechanism. He considered it to add possibilities and freedom.

With regard to stability, Mikkel found that there were issues, but felt that that was a learning issue, given time he felt it would be controllable.

Changing the eq settings while playing was something that Mikkel enjoyed a lot, and felt that an embodied approach to controlling these kind of parameters would be worth exploring.

The pre-sets were an aspect that Mikkel felt would be essential, one would have to find time in a rehearsal room to find what settings worked best, and then be able to dial them in at a concert.

He found it very explorable, and exploring it was the most entertaining part.

James Walford

James remarked that it fun to play

James has a very specific idea of how he wants a snare response to sound, and does not have a great deal of interest in varying it.

The topography of a Caixa (James' main drum) dictates where he can hit, this has affected his technique and mental approach such that he was not interested in exploring localisation.

He also felt that he would have been a better judge had he been a snare player.

The many different programmable parameters meant that he felt he would get lost in searching for sounds and spend less time playing. This reminded me of Perry Cook's rule that programmability is a cures. After discussing this James stated that he thought that DAD was necessarily complex given that it was a prototype, but that the options should be trimmed down in further development.

Mikkel Find

Mikkel was not satisfied with the snare sound, it was not accurate enough, he felt it sounded like a shaker

Mikkel could not pin-point the problem, but did not think it was in the dynamic response. When asked directly about frequency response he indicated that this could be the problem

When it was suggested that the snare mechanism might augment rather than replace the snare Mikkel questioned when he would use it.

Danni Jenssen

Danni was immediately unhappy with the snare mechanism. His immediate suggestion was that it was the frequency response. He felt an urge to try and tune up the resonant skin

He felt it did not sound like an acoustic snare

He suggested that the speaker I had used was not high enough quality

He felt it did not behave like a snare mechanism

The author was able to select settings that sounded, to Danni, similar to a loose snare

In general, Danni likened the synthetic snare mechanism to an *"old school 808 sound"*
Troels Brandt After accompanying Danni playing DAD, Troels felt that it sounded like a snare drum, but he preferred Danni's own drum
Jakob Svensson Mentioned that one of the first pre-sets sounded like a small splash cymbal resting on the batter head

Synthesiser Module
Mikkel Uth Mikkel's comments were very similar to his comments for the snare mechanism.
James Walford James was much more inspired by this module than the snare mechanism. The "old school Sly and Robbie" sounds drew him in to experimentation The ability to localise sounds around an acentric point made more sense to James, his experience of cajon playing was then utilised to explore different sounds in different places on the drum. DAD made more sense to him from this point on. James felt there were more possibilities with the synthesiser module than with the snare mechanism. We felt this might be affected by how far he was into the test – having become more familiar with DAD, but also that the localisation and tonal variation were also a large part of this. It was the sound that drew him into exploration It felt like a new drum because there was a new sound He felt that it was more cajon than caixa, because it was one drum with different sounds in different locations The variety of sounds made this a more complex instrument, consequentially more difficult, but not too difficult

Danni Jenssen Danni felt that the synthesiser module needed space to be effective.

Effects and Sampler
Mikkel Uth Mikkel was fond of the delay, but found the flanger difficult to control. He did not explore longer delay times without prompting, but as his solo shows, longer delay times were a good playground for him
James Walford James did not like the delay function He did not know how or what to use it for He felt the Flanger was not to his taste and that it would not affect his playing for better or for worse He felt the effects had an affect on what styles could be played. He could not imagine using these at a drum carnival, but that they would be well suited to an electro-funk jam
Mikkel Find Mikkel loved the ping pong delay *"I love it! It's crazy"* *Danni Jenssen* Danni felt that the synthesiser module needed space to be effective. He found this the most inspiring aspect of DAD
Thomas Metcalf Enjoyed the Ping Pong delay, but it raised the question of how to control the delay time The effects in general determine what styles of music you end up playing

Believed there was some inconsistency in the sample triggering

Jakob Svensson

Feels that the pingpong dictates the style of the music you can play

Found it difficult to hear the Flanger

General Comments and Suggestions from Participants

Mikkel Uth

Mikkel regarded DAD as different than a snare drum. He did not see it replacing a snare drum, but that it might make a good second snare.

Mikkel suggested that a natural response is not what he would be requiring of such an instrument.

A low quality old fashioned drum synth sound might be appealing to him

Mikkel talked in terms of existing, established EP design paradigms

The concept of DAD actually being built within a drum was very appealing, more so from an interaction perspective than a presentation one.

He suggested an embodied interaction approach for controlling parameters, when asked if he felt this would be restricting the drummers movements, he replied that he might find it a positive challenge. He also suggested that having mappings attached to body position might be an interesting task from a practice perspective.

Over all, Mikkel was not interested in subtlety or understatement from the drum, but consistent mappings without a sense of quantisation were favoured.

The general observation that more mappings leads to more difficulty arose.

Mikkel made the observation that different users have different requirements with regard to many of his comments

James Walford

The Caixa (James' main instrument) plays a very specific role in the samba orchestra. It is highly tuned, with a specific type and number of snare wires that are positioned on top of the drum. This places restrictions on the variety of techniques and sounds that are associated with it. This meant that the differences between DAD and James' instrument were greater than for the other experts.

DAD's batter head was slack in comparison to his own drum. It took him some time to adjust

James observed that he is used to a much louder drum

Localisation of effects and sounds led James into a new mode of interaction. His player model shifted from caixa to cajon and he immediately felt an improvement in his freedom to explore

James felt that the localisation was inconsistent

He felt that the different dynamic ranges of different drummers did not appear to have been a design consideration, and should have been*. Conversely, he stated that he was forced to play more dynamically, and enjoyed that

Mikkel Find

For Mikkel, clarity of sound is engaging in itself

Mikkel liked the way DAD was tuned (acoustically) and thought it was a good drum

Mikkel stated early on, that having localisation of this kind makes it feel like having two instruments in one

He made a reference to the cajon. The similarity being the playing with hands, and there being different sounds (as distinct from variation in sound) in different places

Mikkel felt it was definitely designed for a drummer, to the point where one had to be a drummer (or percussionist) to be able to use it

Far superior to a drum-pad, Mikkel had claimed on his form that he did not play electronic percussion, but states now that he owns a Roland SDP (Model not known) which stays in it's box because it feels like a piece of rubberised plastic. DAD is a drum from the start, so it feels right.

DAD *"has loads of stories to tell"*

The fact that the sound comes from the drum, and when playing with the hands one can feel the vibrations has an impact for Mikkel. It feels interesting and engaging and natural Overall the snare mechanism needs improving, or a physical snare mechanism needs to be added, or it should not be considered as a snare Would be great for someone who does not play a conventional kit such as Trilok Gurtu.
Danni Jenssen DAD was tuned much lower than Danni is used to during the perception tests Danni was the only drummer to notice the topographical markings markings, the room was lit more substantially than any of the others. They led him to explore the drum in the fashion intended Felt that the test would have been easier with more appropriate instrumentation such as someone playing a Moog synth He felt it was more fun to play with beaters because there was less acoustic sound, but he still liked the fact that it had the familiar feel of an acoustic drum He felt there was a discrepancy between the expectations that he had from the acoustic sound of the drum, and it's digital output When playing with hands, he liked the way the sound resonated through his hands. Danni felt it was more than one instrument, given the number of possible settings, and that he would have to spend a great deal of time experimenting He felt that DAD might present most strongly as a stand alone instrument rather than as part of a drum kit. He agreed, when suggested, that it would work better as a second snare than as a replacement snare drum
Troels Brandt Troels felt that the many possibilities made DAD actually more than one drum

He expressed the opinion that DAD would be best shown off to the audience during a solo, without the rest of the kit, and that this could be where the instrument's strength would lie

Thomas Metcalf

Had some previous experience of using triggers, could feel that there was a different sensitivity mapping with DAD

Co/location of sound was not an issue for Thomas, but he did like that with DAD you could balance the sound easily (between acoustic and synthetic)

When using the damping pad, Thomas felt DAD behaved more like a drum pad, he wanted more response from the drum surface

Enjoyed the tactile feedback of the drum when playing by hand

Being able to define zones on the drum was enjoyable for Thomas

He said he would need time to sit and learn how to use the instrument

Suggested that dividing the drum along a centre line would be good for him

DAD gives a new perspective to playing with hands and beaters

Jakob Svensson

Jakob found the last questions difficult, he felt there was a premise that he disagreed with

Enjoyed it enough to try and play it himself. Noted that playing a standard conga pattern with some synth and sampler localised effects enabled completely changes the rhythm pattern

Visual appearance

Mikkel Uth

Mikkel liked the visual appearance, but had reservations about the choice of hardware for the controls... buttons where rotary controllers might be better suited and vice versa

Researcher Observations

Mikkel Uth

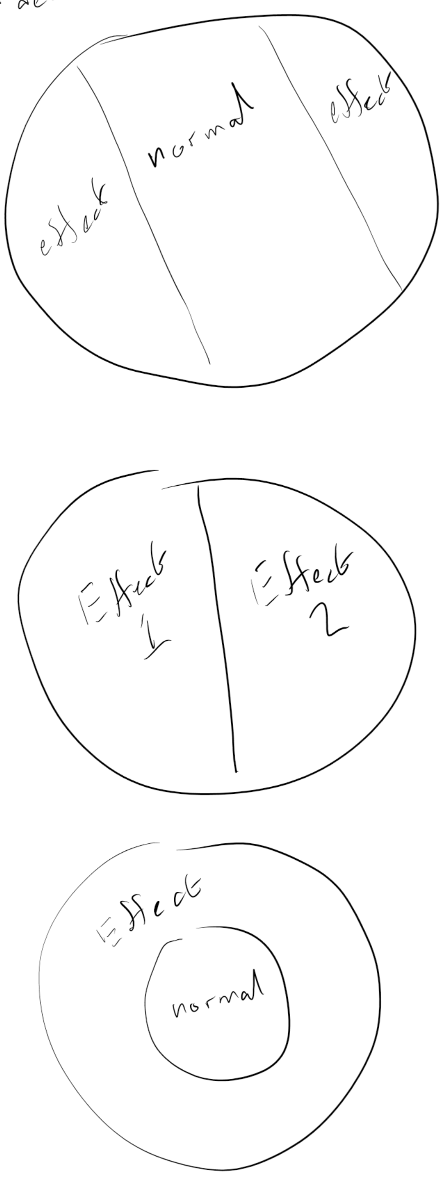
Mikkel favoured sticks to any other kind of interaction, although he did, when prompted, experiment with beaters, brushes and hands. It did not appear natural for him to explore the area of the drum where the acentric sensor was located
James Walford James was not comfortable sitting down, so the snare stand was raised to a very high point and angled to present DAD in a position similar to that of a caixa being worn on a strap. It appeared unstable and may have affected James' sense of freedom. James did not notice that the sound was coming form the drum. When he was prompted for comment he said it felt completely natural
Mikkel Find Mikkel was very quick to find the localisation during the perception tests, and was the only drummer to explore DAD with his hands without prompting Mikkel has a positive attitude, whilst being critical at times, he may score naturally in favour of DAD as a default The synthetic drum tones were noticed from the first perception test, and he commented on it Mikkel identified one of the control parameters (release) during the perception tests During perception tests he remarked that he felt in control of the sound Mikkel is so adept at detecting differences between theses settings and so proactive in exploring the drum, that he learnt some of the system during perception tests, this might affect the numerical data Mikkel loving the ping pong delay, but not knowing what he could use the snare mechanism for suggests that he is not looking for subtlety
Thomas Metcalf Immediately searched the entire head without prompting Had a tendency to only use sticks, although tried beaters, brushes and hands when prompted

Appendix B

Initial Interviews Notes

15 March 2017 08:55

Ideas for localisation



Response

Mikkel – should not be latent ~ with bEADS

Drum stuff

Techniques very personal

Batter head is sacred ground

Tuning varies from drummer to drummer

Centre of batter head should behave 'normally'

Skin tension related to genre

Not sure if skin tension affects feel

Some old drummers can't hit hard

brushes are often too quiet

Don't know what drums sound like off stage

Techniques

Consensus → what is the point in new gesture set?

Response should be consistent if it's consistent drummer

Appendix C

Expert Evaluation Form

General data

This interview is voluntary. You have the right not to answer any question, and to stop the interview at any time or for any reason.

Please continue if you consent to your answers being used for ongoing research.

*Required

1. **Do you mind video being taken?** *
   Mark only one oval.
   - Yes
   - No

2. **Do you object to any video footage being used in a presentation, or further academic research that may or may not involve you?**
   Mark only one oval.
   - No
   - Yes

3. **Name**

4. **Gender**
   Mark only one oval.
   - Male
   - Female

5. **Age**

6. **Main instrument**

7. **How many years have you played percussion?**

8. **Please classify your own playing standard** *
   Mark only one oval.
   - Professional
   - Semi-professional
   - Keen Amateur
   - Novice

9. **Musical Education**
   Mark only one oval.
   - School
   - College
   - University
   - Private Tuition
   - Conservatory

10. **Have you played electronic percussion before?**
    Mark only one oval.
    - No
    - Yes
    - Other:

11. **How confortable are you with technology?**
    Mark only one oval.

	1	2	3	4	5	
Not at all						Very

12. **What genre do you play most often** *

13. **Do you have significant experience playing other genres?**
    Mark only one oval.
    - Yes
    - No

Perception test 1

Please rate your drum, without the snare mechanism engaged, according to the following criteria

14. **Resonance** *
    Mark only one oval.

	1	2	3	4	5	6	7	
Extremely resonant								Not at all resonant

15. **Richness** *
    Mark only one oval.

	1	2	3	4	5	6	7	
Extremely rich								Not at all rich

16. **Clarity** *
    Mark only one oval.

	1	2	3	4	5	6	7	
Extremely clear								Not at all clear

17. **Naturalness** *
    Mark only one oval.

	1	2	3	4	5	6	7	
Extremely Natural								Not at all natural

18. **Engagement** *
    Mark only one oval.

	1	2	3	4	5	6	7	
Extremely engaging								Not at all engaging

19. **Balance** *
    Mark only one oval.

	1	2	3	4	5	6	7	
Extremely balanced								Not at all balanced

20. **Dynamic Control** *
    Mark only one oval.

	1	2	3	4	5	6	7	
Extremely good								Very bad

21. **Playability** *
    Mark only one oval.

	1	2	3	4	5	6	7	
Extremely good								Very bad

22. **General Preference** *
    Mark only one oval.

	1	2	3	4	5	6	7	
The perfect drum								A very poor drum

Perception test 2

Please rate DAD, without the snare mechanism engaged, according to the following criteria

23. **Resonance** *
    Mark only one oval.

	1	2	3	4	5	6	7	
Extremely resonant								Not at all resonant

24. **Richness** *
    Mark only one oval.

	1	2	3	4	5	6	7	
Extremely rich								Not at all rich

25. **Clarity** *
    Mark only one oval.

	1	2	3	4	5	6	7	
Extremely clear								Not at all clear

26. **Naturalness** *
    Mark only one oval.

	1	2	3	4	5	6	7	
Extremely Natural								Not at all natural

27. **Engagement** *
    Mark only one oval.

	1	2	3	4	5	6	7	
Extremely engaging								Not at all engaging

28. **Balance** *
    Mark only one oval.

	1	2	3	4	5	6	7	
Extremely balanced								Not at all balanced

29. **Dynamic Control** *
    Mark only one oval.

	1	2	3	4	5	6	7	
Extremely good								Very bad

30. **Playability** *
Mark only one oval.

	1	2	3	4	5	6	7	
Extremely good	◯	◯	◯	◯	◯	◯	◯	Very bad

31. **General Preference** *
Mark only one oval.

	1	2	3	4	5	6	7	
The perfect drum	◯	◯	◯	◯	◯	◯	◯	A very poor drum

Perception test 3

Please rate DAD, without the snare mechanism engaged, according to the following criteria

32. **Resonance** *
Mark only one oval.

	1	2	3	4	5	6	7	
Extremely resonant	◯	◯	◯	◯	◯	◯	◯	Not at all resonant

33. **Richness** *
Mark only one oval.

	1	2	3	4	5	6	7	
Extremely rich	◯	◯	◯	◯	◯	◯	◯	Not at all rich

34. **Clarity** *
Mark only one oval.

	1	2	3	4	5	6	7	
Extremely clear	◯	◯	◯	◯	◯	◯	◯	Not at all clear

35. **Naturalness** *
Mark only one oval.

	1	2	3	4	5	6	7	
Extremely Natural	◯	◯	◯	◯	◯	◯	◯	Not at all natural

36. **Engagement** *
Mark only one oval.

	1	2	3	4	5	6	7	
Extremely engaging	◯	◯	◯	◯	◯	◯	◯	Not at all engaging

37. **Balance** *
Mark only one oval.

	1	2	3	4	5	6	7	
Extremely balanced	◯	◯	◯	◯	◯	◯	◯	Not at all balanced

38. **Dynamic Control** *
Mark only one oval.

	1	2	3	4	5	6	7	
Extremely good	◯	◯	◯	◯	◯	◯	◯	Very bad

39. **Playability** *
Mark only one oval.

	1	2	3	4	5	6	7	
Extremely good	◯	◯	◯	◯	◯	◯	◯	Very bad

40. **General Preference** *
Mark only one oval.

	1	2	3	4	5	6	7	
The perfect drum	◯	◯	◯	◯	◯	◯	◯	A very poor drum

Perception test 4

Please rate DAD, without the snare mechanism engaged, according to the following criteria

41. **Resonance** *
Mark only one oval.

	1	2	3	4	5	6	7	
Extremely resonant	◯	◯	◯	◯	◯	◯	◯	Not at all resonant

42. **Richness** *
Mark only one oval.

	1	2	3	4	5	6	7	
Extremely rich	◯	◯	◯	◯	◯	◯	◯	Not at all rich

43. **Clarity** *
Mark only one oval.

	1	2	3	4	5	6	7	
Extremely clear	◯	◯	◯	◯	◯	◯	◯	Not at all clear

44. **Naturalness** *
Mark only one oval.

	1	2	3	4	5	6	7	
Extremely Natural	◯	◯	◯	◯	◯	◯	◯	Not at all natural

45. **Engagement** *
Mark only one oval.

	1	2	3	4	5	6	7	
Extremely engaging	◯	◯	◯	◯	◯	◯	◯	Not at all engaging

46. **Balance** *
Mark only one oval.

	1	2	3	4	5	6	7	
Extremely balanced	◯	◯	◯	◯	◯	◯	◯	Not at all balanced

47. **Dynamic Control** *
Mark only one oval.

	1	2	3	4	5	6	7	
Extremely good	◯	◯	◯	◯	◯	◯	◯	Very bad

48. **Playability** *
Mark only one oval.

	1	2	3	4	5	6	7	
Extremely good	◯	◯	◯	◯	◯	◯	◯	Very bad

49. **General Preference** *
Mark only one oval.

	1	2	3	4	5	6	7	
The perfect drum	◯	◯	◯	◯	◯	◯	◯	A very poor drum

Perception test 5

Please rate DAD, without the snare mechanism engaged, according to the following criteria

50. **Resonance** *
Mark only one oval.

	1	2	3	4	5	6	7	
Extremely resonant	◯	◯	◯	◯	◯	◯	◯	Not at all resonant

51. **Richness** *
Mark only one oval.

	1	2	3	4	5	6	7	
Extremely rich	◯	◯	◯	◯	◯	◯	◯	Not at all rich

52. **Clarity** *
Mark only one oval.

	1	2	3	4	5	6	7	
Extremely clear	◯	◯	◯	◯	◯	◯	◯	Not at all clear

53. **Naturalness** *
Mark only one oval.

	1	2	3	4	5	6	7	
Extremely Natural	◯	◯	◯	◯	◯	◯	◯	Not at all natural

54. **Engagement** *
Mark only one oval.

	1	2	3	4	5	6	7	
Extremely engaging	◯	◯	◯	◯	◯	◯	◯	Not at all engaging

55. **Balance** *
Mark only one oval.

	1	2	3	4	5	6	7	
Extremely balanced	◯	◯	◯	◯	◯	◯	◯	Not at all balanced

56. **Dynamic Control** *
Mark only one oval.

	1	2	3	4	5	6	7	
Extremely good	◯	◯	◯	◯	◯	◯	◯	Very bad

57. **Playability** *
Mark only one oval.

	1	2	3	4	5	6	7	
Extremely good	◯	◯	◯	◯	◯	◯	◯	Very bad

58. **General Preference** *
Mark only one oval.

	1	2	3	4	5	6	7	
The perfect drum								A very poor drum

Perception test 6
Please rate DAD, without the snare mechanism engaged, according to the following criteria

59. **Resonance** *
Mark only one oval.

	1	2	3	4	5	6	7	
Extremely resonant								Not at all resonant

60. **Richness** *
Mark only one oval.

	1	2	3	4	5	6	7	
Extremely rich								Not at all rich

61. **Clarity** *
Mark only one oval.

	1	2	3	4	5	6	7	
Extremely clear								Not at all clear

62. **Naturalness** *
Mark only one oval.

	1	2	3	4	5	6	7	
Extremely Natural								Not at all natural

63. **Engagement** *
Mark only one oval.

	1	2	3	4	5	6	7	
Extremely engaging								Not at all engaging

64. **Balance** *
Mark only one oval.

	1	2	3	4	5	6	7	
Extremely balanced								Not at all balanced

65. **Dynamic Control** *
Mark only one oval.

	1	2	3	4	5	6	7	
Extremely good								Very bad

66. **Playability** *
Mark only one oval.

	1	2	3	4	5	6	7	
Extremely good								Very bad

67. **General Preference** *
Mark only one oval.

	1	2	3	4	5	6	7	
The perfect drum								A very poor drum

Perception test 7
Please rate DAD, without the snare mechanism engaged, according to the following criteria

68. **Resonance** *
Mark only one oval.

	1	2	3	4	5	6	7	
Extremely resonant								Not at all resonant

69. **Richness** *
Mark only one oval.

	1	2	3	4	5	6	7	
Extremely rich								Not at all rich

70. **Clarity** *
Mark only one oval.

	1	2	3	4	5	6	7	
Extremely clear								Not at all clear

71. **Naturalness** *
Mark only one oval.

	1	2	3	4	5	6	7	
Extremely Natural								Not at all natural

72. **Engagement** *
Mark only one oval.

	1	2	3	4	5	6	7	
Extremely engaging								Not at all engaging

73. **Balance** *
Mark only one oval.

	1	2	3	4	5	6	7	
Extremely balanced								Not at all balanced

74. **Dynamic Control** *
Mark only one oval.

	1	2	3	4	5	6	7	
Extremely good								Very bad

75. **Playability** *
Mark only one oval.

	1	2	3	4	5	6	7	
Extremely good								Very bad

76. **General Preference** *
Mark only one oval.

	1	2	3	4	5	6	7	
The perfect drum								A very poor drum

Skip to "Introduction of concepts."

Introduction of concepts
1. Experienced freedom and possibilities
2. Perceived control and comfort
3. Perceived stability, sound quality and aesthetics
4. Learnability
5. Explorability
6. Feature controllability
7. User experience
8. Timing controlability
9. Categorisation - instrument like, extended instrument, instrument inspired, alternative instrument, hyper-instrument, active instrument

Snare Mechanism
Each section of DAD's snare mechanism module will now be explained, and you can play around with the settings.

1. On / Off and volume
2. Release effects how long the virtual snare wires continue to vibrate after hitting the drum
3. Localisation. The snare mechanism is set up to to always respond when the drum is struck in the

centre, but you can adjust the mechanism so that it is less sensitive when struck towards the edge. You may have to readjust the volume to make use of this
4. Adjusts the tension, and number of virtual wires, pressing the select button switches between theses two values
5 & 6 adjust an EQ section on the output of the snare mechanism.
7, does not yet work
8, allows you to switch between presets, and store your own

77. **Can we discuss what we have just worked with?**

78. **How was it to perform with the snare effects patch?**
Mark only one oval per row.

	Easy	Fairly Easy	Neither Easy nor Difficult	Fairly Difficult	Difficult
Mentally					
Physically					
Timing					
Frustration					

79. **How engaging did you find the snare mechanism?**
Mark only one oval.

	1	2	3	4	5	
Very engaging						Not at all engaging

The synthesiser
1. Allows you to switch on and off the synth, and to change it's volume
2. Allows you to adjust how long the synthesized sound lasts after hitting the drum
3. Allows you to switch between sensor locations, and adjust sensitivity, similarly to the way the snare mechanism localisation is controlled
4. Allows you to tune up or down
5. Changes the harmonic properties to model different materials
6. Makes it sound like the drum is being dipped in water, press select to switch between rate of dipping and depth of dip
7. Allows you to save and access presets as with the snare mechanism

80. **Can we discuss what we have just worked with**

81. **How was it to perform with the synth patch?**
Mark only one oval per row.

	Easy	Fairly Easy	Neither Easy nor Difficult	Fairly Difficult	Difficult
Mentally					
Physically					
Timing					
Frustration					

The Effects

1 and 2 allow you to switch on and off, and change the delay line on two delays, they only work on the output from the snare mechanism and the synthesiser
3, 4 and 5 control a flanger effect that can dramatically change the sound of the drum
Presets have not been set up

The sampler

1 here you switch on and off, and control the volume of the sample
2, here you can choose which sample to load,
3, some localization controls
4. You can change the direction of the sample
5 and the speed

82. **Can we discuss what we have just worked with - the effects and sampler modules?**

83. **How was it to perform with the ping pong delay?**
Mark only one oval per row.

	Easy	Fairly Easy	Neither Easy nor Difficult	Fairly Difficult	Difficult
Mentally					
Physically					
Timing					
Frustration					
engagement					

84. **How was it to perform with the flanger?**
Mark only one oval per row.

	Easy	Fairly Easy	Neither Easy nor Difficult	Fairly Difficult	Difficult
Mentally					
Physically					
Timing					
Frustration					
engagement					

85. **How was it to perform with the sampler?**
Mark only one oval per row.

	Easy	Fairly Easy	Neither Easy nor Difficult	Fairly Difficult	Difficult
Mentally					
Physically					
Timing					
Frustration					
Engagment					

Can you please play a short solo

First on DAD, then or your own instrument

Is it OK if it is video recorded

Also just play some single hits on your own instrument

Comparsion to your own instrument

86. **Which is best in terms of...**
Mark only one oval per row.

	DAD	Your own drum
Freedom and possibilities		
Perceived control and comfort		
Stability sound quality aesthetics		
Learnability		
Explorability		
Controllability		
Overall Experience		

87. **If DAD had been built from a better drum, would the outcome have been any different?**

SUS

88. **I think that I would like to use this instrument frequently**
Mark only one oval.

	1	2	3	4	5	
Strongly agree						Strongly disagree

89. **I found the instrument unnecessarily complex**
Mark only one oval.

	1	2	3	4	5	
Strongly agree						Strongly disagree

90. **I thought the instrument was easy to use**
Mark only one oval.

	1	2	3	4	5	
Strongly agree						Strongly disagree

91. **I think that I would need the support of a technical person to use this instrument**
Mark only one oval.

	1	2	3	4	5	
Strongly agree						Strongly disagree

92. **I found the various functions in this instrument were well integrated**
Mark only one oval.

	1	2	3	4	5	
Strongly agree						Strongly disagree

93. **I thought there was too much inconsistency in this instrument**
Mark only one oval.

	1	2	3	4	5	
Strongly agree						Strongly disagree

94. **I would imagine that most people would learn to use this instrument very quickly**
Mark only one oval.

	1	2	3	4	5	
Strongly agree						Strongly disagree

95. **I found the instrument very cumbersome to use**
Mark only one oval.

	1	2	3	4	5	
Strongly agree						Strongly disagree

96. **I felt very confident using the instrument**
Mark only one oval.

	1	2	3	4	5	
Strongly agree						Strongly disagree

97. **I needed to learn a lot of things before I could get going with this instrument**
Mark only one oval.

	1	2	3	4	5	
Strongly agree						Strongly disagree

Final questions

It's nearly over

98. **Basic tasks**
Tick all that apply.

- [ ] Can you play with a steady tempo?
- [ ] Can you incorporate a localised sound into a pattern
- [ ] Can you play freely
- [ ] Is it possible to quickly change timbre
- [ ] Are you able to make musical use of variation in sound
- [ ] Are you able to play dynamically
- [ ] Are you able to use a good variety of techniques and still make use of DAD's features

99. **Any further comments or suggestions?**

Appendix D

Technical Manuals

Relevant excerpts from manufacturer data sheets and manuals are presented on the following pages:

1. QRE1113 Reflective object sensors
2. Rode NT2-A Microphone
3. Pioneer Mid Range Loud Speaker
4. Dayton Audio 20 W Audio Exciter

Typical Performance Curves

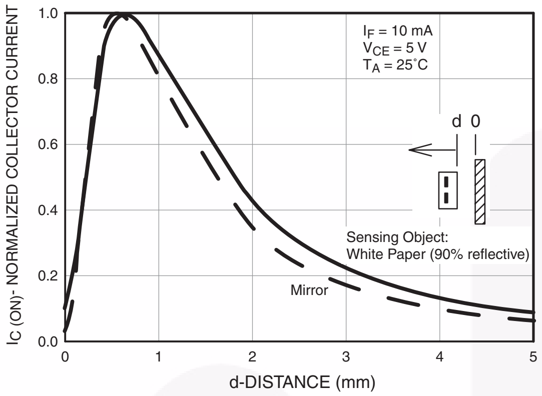


Fig. 1 Normalized Collector Current vs. Distance between device and reflector

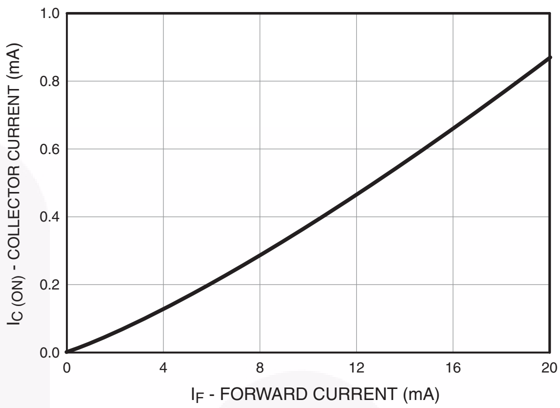


Fig. 2 Collector Current vs. Forward Current

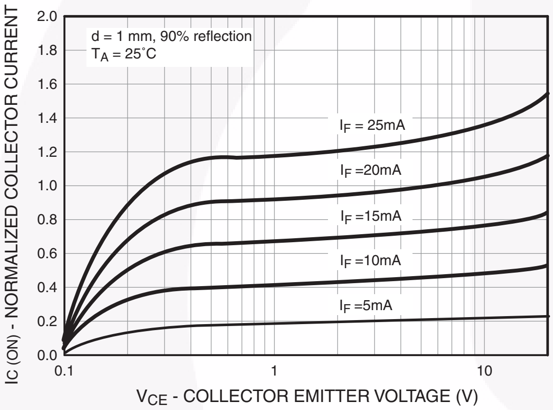


Fig. 3 Normalized Collector Current vs. Collector to Emitter Voltage

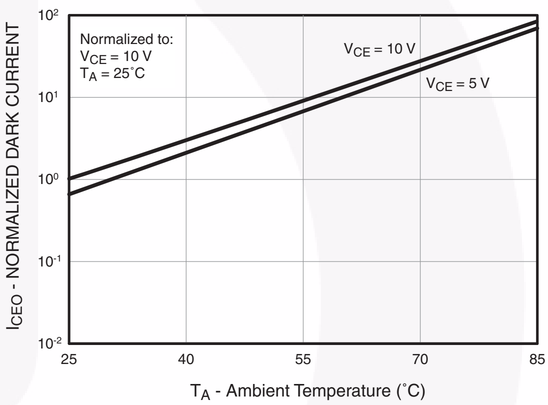


Fig. 4 Collector Emitter Dark Current (Normalized) vs. Ambient Temperature

Typical Performance Curves (Continued)

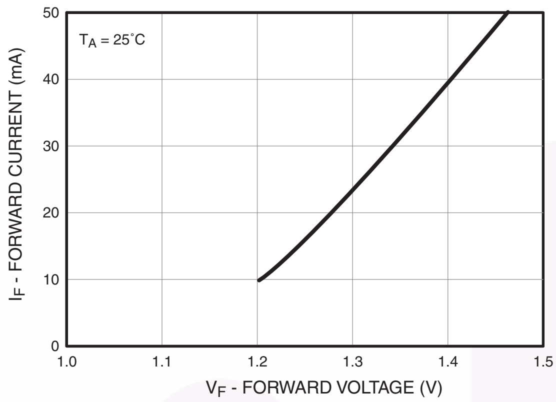


Fig. 6 Forward Current vs. Forward Voltage

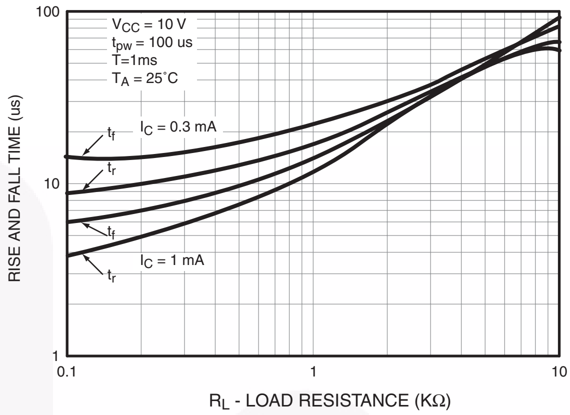


Fig. 7 Rise and Fall Time vs. Load Resistance

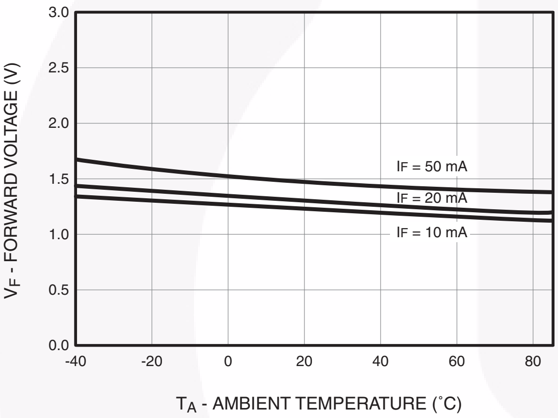


Fig. 8 Forward Voltage vs. Ambient Temperature

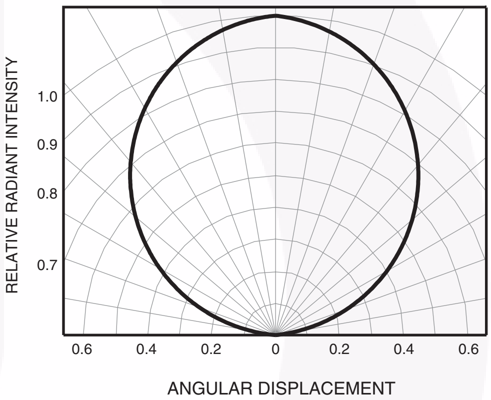


Fig. 8 Radiation Diagram

NT2-A

Multi Pattern 1” Condenser Microphone

AUSTRALIA
107 Carnarvon st, Silverwater NSW 2128 Australia
Ph: +61 2 9648 5855 Fx: +61 2 9648 2455

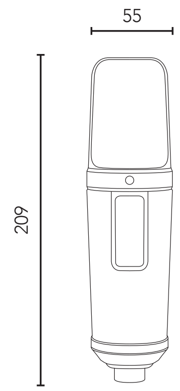
USA
PO Box 91028, Long Beach CA 90809-1028
Ph: +1 562 364 7400 Fax: +1 888 412 4664

Features

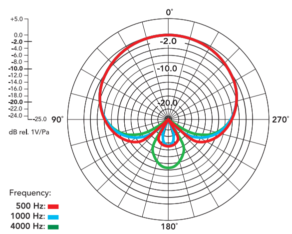
- Large 1” (25mm) HF1 gold sputtered capsule
- On body control of polar pattern, HPF and PAD
- Three position variable polar pattern - Omni, Cardioid or Figure 8
- Three position variable High-Pass Filter - Flat, 40Hz or 80Hz
- Three position PAD - 0dB, -5dB or -10dB
- Ultra low noise, transformerless surface mount cicuitry
- Includes SM6 shock mount with integrated pop filter, 3m XLR cable, dustcover and exclusive training DVD.
- Internal capsule shock mounting
- Designed and manufactured in Australia
- 10 year warranty*

Specifications

Acoustic Principle	Pressure, Pressure gradient
Directional Pattern	Three position variable - Omni, Cardioid or Figure 8
Frequency Range	20 Hz-20 kHz
Sensitivity	-36 dB re 1 Volt/Pascal (16 mV @ 94 dB SPL) +/- 2 dB @ 1kHz
Output Impedence	200Ω
Dimensions	Length - 209mm (8.2283”) Diameter - 55mm (2.1653”)
Output Connection	3 pin XLR, balanced output between Pin 2 (+), Pin 3 (-) and Pin 1 (ground)
Shipping Weight	1kg
Net Weight	860g



Polar Pattern



Cardioid

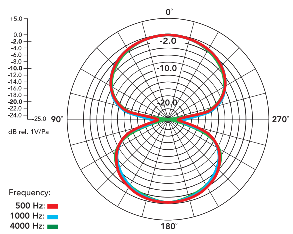
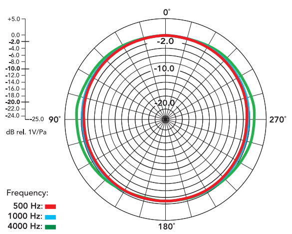


Figure 8



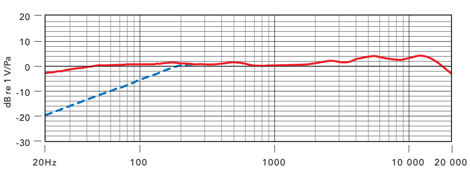
Omni

Accessories

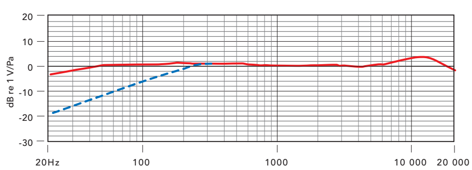
- SM6 Shock mount
- 6m XLR cable
- Microphone dustcover
- Exclusive NT2-A training DVD

Frequency Response

Cardioid



Omni

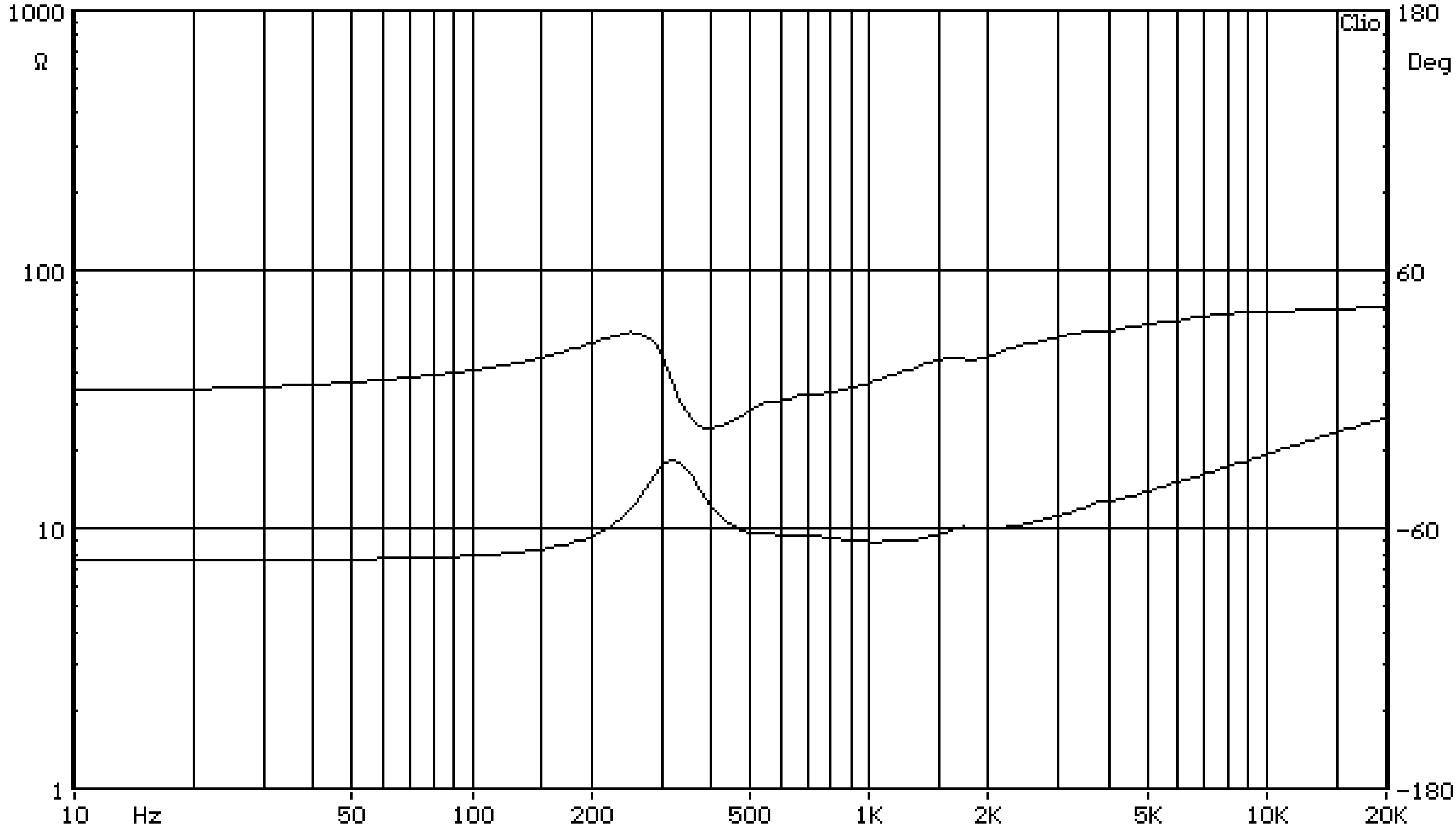


Notes

*Microphone must be registered at www.rodemic.com to activate extended warranty.

RØDE MICROPHONES

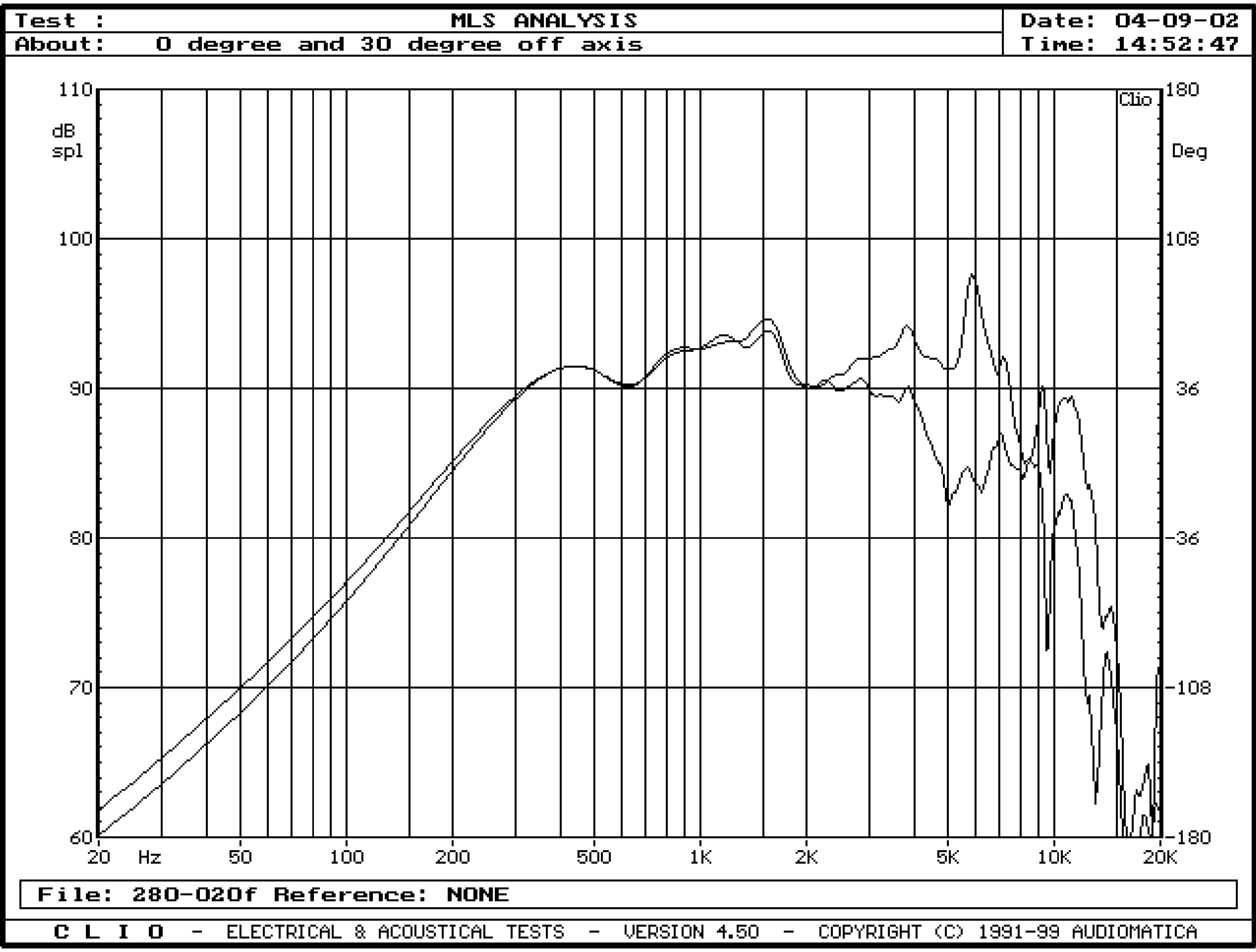
Test : IMPEDANCE RESPONSE & PARAMETERS	Date: 04-09-02
About:	Time: 14:56:38



MANUFACTURER : Pioneer MODEL : 280-020

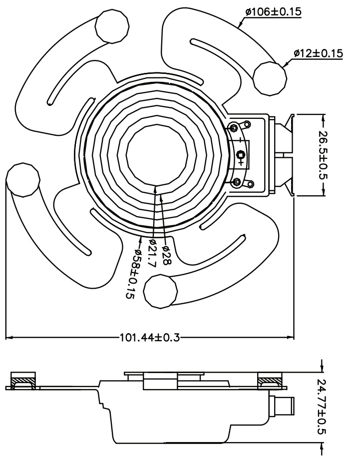
D : 0.00 [mm]	Qms : 2.58	Mms : 0.00 [g]	Bl : 0.00	[N/A]
Re : 7.10 [Ω]	Qes : 1.85	Cms : 0.00 [mm/N]	L1K : 0.77	[mH]
Fs : 325.52 [Hz]	Qts : 1.08	Vas : 0.00 [l]	L10K : 0.27	[mH]

File: 280-020z


Test :
MLS ANALYSIS
Date: 04-09-02
About: 0 degree and 30 degree off axis
Time: 14:52:47
110
dB
spl
100
90
80
70
60
180
Deg
108
36
-36
-108
-180
Clio
20
Hz
50
100
200
500
1K
2K
5K
10K
20K
File: 280-020f Reference: NONE
C L I O - ELECTRICAL & ACOUSTICAL TESTS - VERSION 4.50 - COPYRIGHT (C) 1991-99 AUDIOMATICA

DAEX25Q-4

Quad Feet 25mm Exciter 20W 4 Ohm



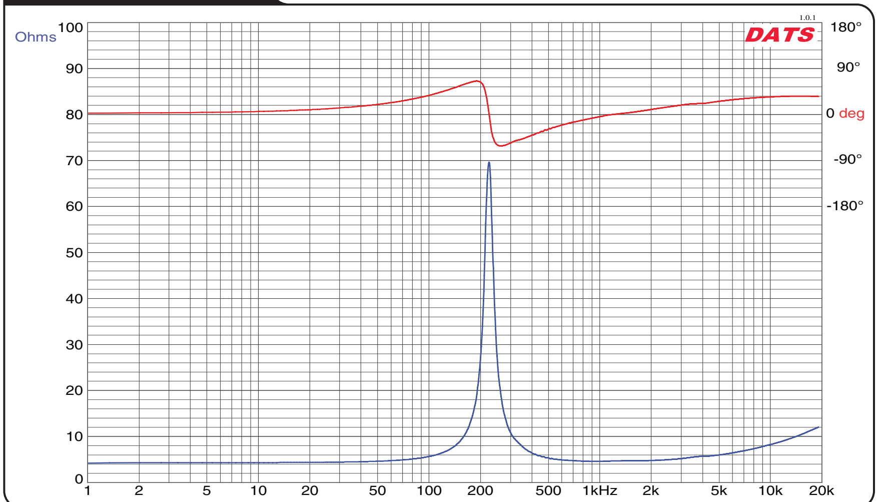
Features

- Wideband frequency response
- 3M adhesive pads
- Enhanced quad-feet mounting

Applications

- Hidden sound
- Home and office audio
- Windows and point of sale

Impedance Plot



Parameters

Impedance (Ω)	4
Re (Ω)	4.3
Le (mH) @ 1 kHz	0.25
Fs (Hz) - Uncoupled	224
Qms	—
Qes	—
Qts	0.69
Mms (g)	1.75
Cms (mm/N)	0.0003
Sd (cm^2)	—
Vd (cm^3)	—
BL (Tm)	3.86
VAS (liters)	—
XMAX (mm)	—
VC Diameter (mm)	25
Net Weight (g)	90.5
RMS Power Handling (W)	20
Usable Frequency Range (Hz)	*

  Last Revised: 2/5/2014

Note: All dimensions in mm.

****Frequency response varies by application.***