Motorique - Control of Tempo and Frequency for Modular Synthesizers through Modulation of Rotational Motor Wheel Speed

Prototyping of a Eurorack Module for Investigation into Motor Speed as a Representation of Musical Tempo and Frequency

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Abstract:

In this thesis, the design, implementation and evaluation of a digital musical interface (DMI), specifically for the Eurorack modular synthesizer format, is described in addition to a review of different options for evaluating DMIs, related devices and musical context.
Motorique is a DMI that allows motor speed control of tempo and frequency. The relationship between tempo, frequency and motor speed is explored, in musical terms, in order to ascertain whether this is a novel or interesting form of interaction. Its design is heavily influenced by musical playback devices with rotating surfaces such as turntables and tape machines. With many electronic musicians having prior experience with these types of devices, the need for further experimentation with tempo modulation as a form of musical expression in electronic and more specifically dance music is discussed.
Usability Testing and video-cued recall is used to obtain both quantitative and qualitative data (mixed method) during evaluation.

Contents

Preface

Many thanks to everyone at Bastl Instruments, my supervisors and other helpful AAU staff, family and friends (especially my fellow SMC students and the 2TH/3TH extension boys) and various members of the Teensy forum (most notably Paul Stoffregen and mxmxmx) without whom, this project would not have been possible. A special thanks goes to anyone that created music that I listened to while writing this thesis for the constant sources of inspiration.

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Chapter 1

Introduction

The advent of digital audio workstations (DAWs) has meant some professional producers, musicians and mastering engineers now solely use software, due to its portability. DAWs can be used for making music on laptops, liberating the possible locations in which creation and production of music can take place, whereas in the past this was largely constrained to studios. Affordability is another large factor in the rise in popularity of using DAWs, as users now do not need a full studio of equipment (mixing desk, or even physical instruments due to the advances in sampling and synthesis technologies) in order to make music. One major positive outcome of this innovation can be seen in the formation of contemporary genres of electronic music such Shangaan Electro and Gqom in South Africa. The reduced cost of equipment, with essentially just a computer and the internet being needed to make and share music, rather than a full studio of equipment, has opened the possibility of making electronic music for a new generation. In addition to enabling access to electronic music production tools for communities where previously it may have been out of reach monetarily. As Gqom producer Tonic Jazz (of the group Illumination Boyz) discusses, "Gqom is a DIY sound, and most of the people who produce Gqom music, they come from townships. They use bootleg software" [1]. Although some may argue that accessibility to DAWs have caused an over saturation of the market, especially in terms of electronic music, it is evident that music production and recording technologies are more accessible than ever before for people worldwide.

Digital musical interfaces (DMIs) are devices for performance or interaction with digital audio and or synthesis and come in a variety of different forms. One of the more common purposes for creating a DMI is to offer a link between input (pressing a key on a keyboard) and output (the resulting sound) for a digitally based musical instrument or interface. DMIs frequently come in the form of a tangible piece of hardware. A common example of a DMI is a MIDI keyboard[1] that can be used for playing and recording notes into a DAW, however the range of devices within

[1] Musical Instrument Digital Interface - An industry standard protocol, created in 1983 that allows communication between various hardware devices including computers. MIDI also refers to the cable used for connecting these devices, a file format, and digital musical instruments and interfaces.

the field is incredibly diverse and varied. A common theme among many DMIs is the need to provide some form of tactile or haptic feedback to the user, which is often inspired by acoustic instruments and largely lost when just using a mouse and computer keyboard. Percussion synthesis is an area of music creation where many performers often opt for "the tactile interaction provided by using a hardware controller to program drum tracks" [2].

For this project, a DMI will be designed and created for the Eurorack format of modular synthesizers. The Eurorack format was invented by German company Doepfer in 1995 and has rapidly gained popularity compared to older modular formats. This is due to many more manufacturers starting production, from small boutique companies like Bastl Instruments[2] to multinational companies like Roland now producing their own Eurorack modules. There is also an emerging do-it-yourself (DIY) community and aesthetic surrounding this technology both online and through modular meetups and workshops. DIY kits for many instruments can be bought, soldered and assembled at home by the consumer allowing savings for both the consumer and manufacturer. Their popularity has increased rapidly with the increase in popularity of the Eurorack format, with many manufacturers now selling them.

The module will be designed using breadboards, and it will be used to send clock speed - square wave LFO (Low Frequency Oscillator) control voltage (CV) signals, in addition to other LFO waveforms and audible range oscillators (VCO - Voltage Controlled Oscillator) to other modules or used as a standalone instrument. The interface will feature two rotating DC motors, each of which will be used to set the frequency of the LFOs or oscillators. This can be altered manually through touching the motor or by using controls to change the tempo that will be sent to control other modules such as a sequencer. The motivation for this project was largely derived from an interest in the connections between speed, rotation, tempo and frequency. Motivation for the project also stemmed from a previous project where an interface was designed for controlling a Max patch, with the intention to reintroduce tempo manipulation as a compositional and live performance technique in electronic and dance music.

Dance music tracks rarely change tempo on a per track basis due to the DJ-centric nature of the genre; most DJs prefer a fixed tempo for each track to make mixing and beatmatching possible and predictable. However, this means that dance music often ignores a useful and compelling compositional tool. While this could also be said of most popular music also, classical composers such as Beethoven, Mozart and Shostakovich use this technique of changing tempo to great effect. However, an innovative and early example of this technique being used in a dance music recording is 'French Kiss' by Lil Louis, released in 1989. The track slows down dramatically during its breakdown and then speeds back up to its initial tempo. Other examples of this in dance music include 'Thousand' by Moby (1993), which constantly increases in tempo up to 1000 BPM and more recently, 'Reloadz' by Terror Danjah, which increases from approximately 140 BPM (a typical tempo for the electronic music

[2]The author of this thesis previously completed an internship at Bastl Instruments.

genre, Grime), to 170 BPM (a typical tempo for the electronic music genre, Drum and Bass). The tempo in 'Reloadz' then decreases to 140 BPM towards the end of the track. One of the reasons tempo changes are used infrequently in dance music is discussed by Solberg, "In EDM, tempo changes are seldom made; the dancers needs a steady and predictable framework on which they can rely and improvise within", and that "by constantly dividing the note value, the DJ or EDM producer gives the illusion and the effect of a tempo increase, affording a greater intensity without the dancer being uncertain about the beat." Solberg titles this the "drum roll effect" [3].

One contemporary group who make thorough use of tempo changes both in live performances and in their recorded material is Second Woman (Joshua Eustis and Turk Dietrich). They make use of this technique and variations upon it over the course of two LPs released in 2016 and 2017. They discuss the opening track of their debut album, "At least for this first grouping of records, where we really wanted to start exploring time distortion, time dilation, space dilation, these kind of ideas — that song is the mission statement"[3]. They then discuss their process and ideas behind the project more generally, "We both felt that over the past decade we've become a slave to song structure, to tempo. [...] I think we missed some of the things that we used to talk about and do musically. [...] Having tempo be malleable, for me leads to a more interesting experience as a listener — I don't know what's coming next" [4]. Here, Eustis and Dietrich discuss the unpredictability of music that does not follow a static tempo and the importance of this this as part of their ongoing evolution of practices for electronic music production and performance. Two of the major influences for the Second Woman project are the experimental electronic music groups, Autechre and SND (and the solo work of Mark Fell), both of whom explore tempo distortion, dilation and malleability in their work.

An earlier example of tempo changes in electronic music is 'Piano Phase' by Steve Reich. In this composition (that can be performed using two tape recorders or pianos) two sequences of notes are played in unison, one of the sequences then speeds up until the first and second notes of the sequence are played at the same time, the faster sequence then returns to the initial tempo. Reich titled this 'process music' and the technique as 'phasing.' This is repeated until the two sequences are again playing in unison. These techniques are used more frequently in live performance of dance music as clock speed between instruments can be synchronized (through MIDI, CV, etc), making tempo shifts easier to control than when DJing.

A number of different frameworks for evaluating musical interfaces will be reviewed and compared. Elements from different frameworks will be combined to gain valuable insights from participants. The inherent value and usefulness of the module for various musicians will be evaluated.

[3]Time dilation is an integral part of Einstein's theory of relativity, whereby the amount of time passed will appear to be different from two viewpoints if gravitational forces on the each viewer differ. Another cause of this phenomenon is due to two objects moving at different velocities in relation to each other. However, details of this are beyond the scope of this project.

1.1 Problem Statement

Interacting with Eurorack modules largely involves altering various parameters on modules through a combination of button presses, switches and potentiometers. A large range of different modules exist, some using less traditional sensors for control of parameters. One of the main appeals of modular synthesizers is the ability for the user to create a system of their own configuration. Within this scope, users are able to patch the system in a multitude of different ways in order for the system to function as intended or to pursue new areas for composition, experimentation and improvisation.

However, as Oliver Gillet, founder of Mutable Instruments (a prominent manufacturer of Eurorack modules), cautions, “using more exotic interface components prominently on synthesis modules - such as force sensitive resistors, touch plates, ribbons, joysticks, etc., will alienate some musicians who prefer other elements.” “Control and synthesis don’t have to happen in the same modules - the beauty of modular systems is that the interface can be completely decoupled from the synthesis” [5]. In this regard the device that will be explored throughout the thesis will be both an interface for control of tempo (through it acting as a clock source) and a module for synthesis. However, modulating tempo by manipulating a DC motor is a relatively new area and the hope is that this will develop new techniques and practices for future experimentation. There are plans to allow the interface and synthesis to be decoupled with a switch in a future iteration of the module, in addition to adding CV input as well as output.

One of the main aims of this project was to create a rotating tactile interface that would allow the user to manipulate signals (specifically clock signals) sent to other modules. The rationale for this is to explore humans’ cognitive coupling of rotation and speed. For example, if the wheels of a car or bicycle appeared to rotate faster, yet this caused the car to slow down, it would be perplexing for the viewer due to our preconceived notions of links between rotation and speed. It would most likely be thought of as an optical illusion. Therefore, speed and rotation are linked perceptually, yet in the context of DMIs this is a relatively unexplored area in terms of tactile interaction. Examples of similar DMIs (and older instruments) will be discussed in the following sections.

One inspiration for exploring this area was the fact that speed and pitch are coupled and can be manipulated on a turntable playing vinyl records, in various ways through controls on the device, or manually by interacting with the platter in different ways.

The module that this thesis will be based on will be an attempt to reintroduce tempo changes into dance music, both as a compositional and improvisational tool in the hope that it can further the evolution of popular, experimental, dance and electronic music. Therefore the problem that this project seeks to address is whether interaction with rotational speed for controlling tempo and frequency due to their perceptual coupling is novel and engaging and whether it can be used as a basis for improvisation.

1.2 Research Question

The main research question that this thesis will seek to answer is whether interaction with a rotating interface for manipulating frequency (audible or infrasound) is necessary or useful for performers and composers?

1.3 Target Group

The target group will be Eurorack users looking to introduce real-world control and perception of tempo and speed into their systems. While this approach may seem like a novelty for some Eurorack users, it has also rarely been investigated. Therefore, it is an instrument that may need to be tried to gauge whether the user would like to incorporate it into their system and working practices. The hope is that the module will encourage Eurorack users and electronic musicians in general to use tempo changes more frequently as a live performance, compositional and improvisational tool.

Chapter 2

Background Research, Related Work and Designs

Developing digital instruments enables musicians to find new ways of expressing themselves. As Holmes discusses, "Improvisation in electronic music is a 45-year old tradition going back to the late 1950s. Its practice has benefitted from the evolution of smaller and more compact electronic instruments and computers. The widespread growth of digital sampling, keyboards, turntables, and other real-time audio processing technology has formed entirely new subculture of music based on live electronic performance, including hip-hop, techno, and electronica, all of which are sustained by the social settings of raves, clubs, and other performance events" [2]. The overall relevance of this chapter is to outline that unless a musician has access to a piece of technology, they cannot improvise in order to develop their own techniques and that new devices can indeed form new types of musical interaction, expression, performance and composition. Below is a discussion of related technological and compositional milestones that have influenced the current project.

2.1 Compositional Tools and their Relation to Improvisation

Prior to the invention of recording technologies and recorded music mediums, classical music composers relied on musical notation and scores in order for their work to be reproduced and performed in different locations. As renowned Jazz pianist Bill Evans argues, "In the seventeenth century there was a great deal of improvisation in classical music, ... and because of the fact that there were no electrical recording techniques or any way to permanize or to catch music, ... the music was written so that it could be permanized that way. And so, slowly but surely, the writing of the music and the interpreters of the written music gave way to more and more interpretation and more and more cerebral composition and less and less improvisation, until finally improvisation became a lost art in classical music and we have only the composer and the interpreter, so the composer even very seldom improvised, or they didn't have to, ... around the late 1800s, or the turn of the century. But Jazz in a way has resurrected that process. Which I call the Jazz process" [6].

Evans continues, "Any good teacher of composition... will always tell the student that the composition should sound as if it's improvised, it has a spontaneous quality" [6]. In the context of electronic and dance music, this is an interesting concept. Repetition is used often in electronic music as a way to provide familiarity to the listener and often as a basis for dancing, this can however make electronic (especially dance music) compositions seem very predefined and predictable, the opposite of what Evans discusses above.

While Evans here argues that Classical composition suffered from a lack of improvisation, this does not mean that composers were not furthering composition in new and interesting ways. One example of innovation and experimentation in composition is Conlon Nancarrow, who used mechanical player pianos as a way to compose music essentially unplayable by humans [7]. This had a large influence on electronic music composition, in that many pieces would be impossible to perform by one (or more) person without the use of sequencers or backing tracks. The genre of black MIDI takes this concept to the n-th degree by trying to include as many notes as possible in a composition, often at very high tempos. As Callender discusses, "Nancarrow turned to mechanical means of realizing his musical ideas in part due to the difficulties performers had in playing his rhythmically challenging music" [8].

2.2 Related Historical Designs

Another composer who used machines in order produce music not possible by performers, was Raymond Scott. Initially, a composer and big band leader, he composed Jazz instead of creating frameworks for improvisation as is normal in Jazz. When his quintet was rehearsing his compositions, Scott "would allow his players to improvise certain sections, ... when they did a solo he liked, he said "freeze it, play it like that every time from now on." This need for control over every element of his compositions continued into his innovative work with early sequencers and synthesizers. As Grammy and Oscar winning film composer, John Williams, says of his work, "the fact that he didn't want improvisation, immediately puts him at opposition with the whole principle of what Jazz really is" [9] and is in direct juxtaposition to the issues discussed by Bill Evans above. Interestingly, perhaps one of Scott's most notable designs, the Electronium, was a system for autonomous composition, a collaboration between machine and composer. First developed in 1959, it predates Aiva (Artificial Intelligence Virtual Artist), the first AI to be officially recognised worldwide as a composer by fifty-eight years [10].

Another similarity between Nancarrow and Scott's work is the influence of player pianos. Scott actually first learned to play piano at a young age through closely observing a player piano (the punch holes in the piano roll and how this created different melodies, rhythms and harmonies) in a musical instrument store close to his childhood home. As the owner discusses, “we had a player piano in the shop, but (he) learned to play the piano by following the notes as they were played by this player piano” [9].

Scott also claims to be the original inventor of the sequencer, “It is not widely known who invented the circuitry concept for the automatic sequential performance of musical pitches – now well known as a “sequencer.” I, however, do know who the inventor was – for it was I who first conceived and built the sequencer” [11]. He called this device, the Circle Machine (Fig. 2.1). However, he later lamented his notoriously secretive working practices, “Now, with the passing of years, I guess I regret my secrecy and would like for people to know of what I accomplished” [11].

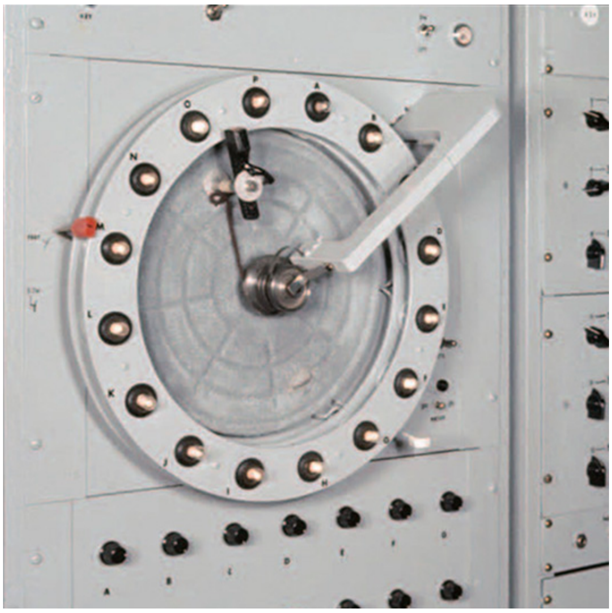


Figure 2.1: Raymond Scott’s Circle Machine. [11]

A more contemporary instrument designer and musician using rotating mechanised means for creating music is Graham Dunning. He uses a combination of turntables, locked groove and custom made vinyl records and piezos for triggering percussion and sounds from a drum module. Interestingly, in 1959, the same year as Scott invented the Circle Machine, the first commercially available drum machine was released by Wurlitzer, the Sideman 5000. Kirn relates the device to Dunning’s work, “The world’s first commercial drum machine, while hardly a huge success, itself used mechanical discs to generate rhythms – very much related. I like to say that the repetitive patterns in techno are related to physical motion in the body, perhaps even the body’s internal rhythms. But here is another way to imagine it – that these rhythms can emerge from real or hypothetical physical processes. The musical is mechanical” [12].

Dunning continues to detail his process, “Using Mechanical Techno set-ups I aim to release the Ghost in the Machine. Each set-up is unique. The technique is inherently clumsy and delicate, leading to frequent and multiple mistakes and accidents. The chance elements and unpredictable aspects lead to compositions I would never think to deliberately make" [13].

Importantly Dunning, refers to his use of a turntable as an instrument in its own right, "It's viewing the record player as an instrument itself, not a messenger. These earlier experiments, from a hacked turntable with a variable speed as slow as 16rpm to about 180rpm (instead of the standard settings of $33\frac{1}{3}$ and 45) to dropping marbles on a spinning record, would eventually inform the Mechanical Techno project." [14].

An example of someone who has used similar techniques as the basis for a production is John Oswald with his work in plunderphonics. Chris Cutler discusses his process in detail, "John Oswald's version of Dolly Parton's version of "The Great Pretender" (is) effectively a recording of Oswald playing Parton's single once through, transformed via a varispeed media (first a high speed cassette duplicator, then an infinitely variable speed turntable, finally a hand controlled reel-to-reel tape – all seamlessly edited together.)" Plunderphonics is a consciously self-reflexive process and experiments solely with existing recordings and the 'already played'. It does not assist, but challenges our notions of originality, individuality and copyright [15]. The concept of plunderphonics could be seen as an elaboration or continuation of techniques used in turntablism, musique concréte, tape music and of Steve Reich's concept of phasing.

Pauline Oliveros used an amalgamation of technologies in her 1965 composition 'Bye Bye Butterfly'. This incorporated the use of two tape recorders organised into a tape delay arrangement and a turntable with record. Its title is a reference to 'Madame Butterfly' by Puccini, "which was at hand in the studio at the time and was spontaneously incorporated into the ongoing compositional mix" [16].

Improvisation and unstructured use of a DMI can encourage the user to interact with the interface in unexpected ways. Whereas, when specific tasks are asked to be completed during testing, there is not so much capacity for improvisation and exploration of the interface. Contextualisation of the current project can be found through the above examples, through their improvisational and compositional nature, and their relationship to the discussed technologies.

2.3 Relevant Modular and Digital Musical Interfaces

The Eurorack modular synthesizer format was invented by German company Doepfer and has rapidly gained popularity compared to older modular formats. This is partly due to the number of new manufacturers starting to produce modules in various varieties. Smaller boutique companies such as Bastl Instruments and multinational companies like Roland, now produce their own Eurorack modules. There is also an emerging do-it-yourself community and aesthetic surrounding this technology both online and through modular meetups and workshops. DIY kits for many instruments can be bought, soldered and assembled at home by the consumer allowing savings for both the consumer (the cost of an instrument) and manufacturer (the time, money and resources for assembling and soldering a pre-made instrument). Their popularity has increased rapidly with the increase in popularity of the Eurorack format, with many manufacturers now selling them.

One of the main appeals of modular synthesizers is that a user can create their own instrument, combining many different modules in a case and different patching methods to create a compact instrument of their own configuration (in comparison to using many separate desktop synthesizers and drum machines). Also, most desktop synthesizers and drum machines come 'pre-patched', so while they can still be incredibly complex, many are limited in that they are not intended to be re-routed internally. The manufacturer's configuration and intended use is final and although many options are usually given within this frame, it cannot be reconfigured from scratch without disassembling the device. This is largely to prevent incorrect connections being made, which could damage the device. However, there are digital versions of modular synthesizers such as the Nord Modular and programs such as Max, Reaktor, PureData and VCV Rack that recreate the ways in which a modular synthesizer can be used.

Tony Rolando, founder of Make Noise, one of the most popular Eurorack companies, discusses his choice to have no screens on modules for visual feedback of parameters, "Unfortunately the screen also takes the user out of the moment because the screen most resembles mundane, everyday life. We must come to terms with the fact that anybody who has afforded themselves a synthesizer has already afforded themselves a smartphone and a laptop and that person will use these devices more than anything else they own. Why would we want music performance to become so related to the mundane tasks of everyday life?" [5]. While during the design process for certain modules, sometimes it may seem unavoidable to omit a screen (for example navigating through samples on a module). The module that will be produced will also not feature a screen and while this will limit the feedback given to the user in various ways, aesthetically it is an important choice. The user must use their real-world experience of rotation and tempo in order to perceive this, rather than a beats per minute being displayed on a screen.

Vaclav Pelousek, one of the founders of Bastl Instruments and the inventor of their Eurorack modules, researched the translating of "biological, mechanical and chemical principles into electronic music and vice-versa" for his Master's thesis. During this thesis, Pelousek outlined and produced various Eurorack prototypes and schematics for future modules that both react to (ASCM - Analog Sensor Calibration Module, Simple Trigger and Geiger Counter to Trigger and CV) and cause (VCMD - Voltage Controlled Motor Driver, CV 2 Servo and Trigger 2 Solenoid) real-world phenomena. Pelousek then continues to suggest uses or methods for patching the modules together to create events or systems that both react to and cause biological, mechanical or chemical phenomena. One of the proposed mechanical systems is the Fan VCO (Fig. 2.2), "the light passing through a CV controlled fan (by VCMD module) is gated by the propeller and results into audible signal (when sensed by light dependant resistor

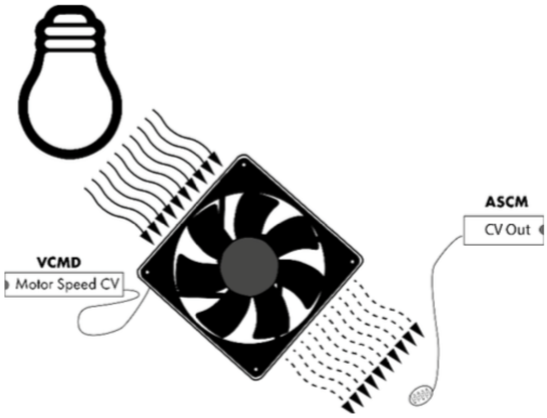


Figure 2.2: Vaclav Pelousek's Version of the Fan VCO. [17]

and amplified by the ASCM module) [17]. The proposal of this system was highly influential to the current thesis project. Four of these prototypes later became Bastl Eurorack modules: Sense, DC Motor, Servo and Solenoid modules.

As Pelousek mentions of the Fan VCO, "This module was originally developed by Gijs Gieskes who is a big inspiration for this whole research" [17]. Gieskes produces a number of unique Eurorack modules; in addition to both versions the VCO Fan, the Voltage Controlled CD Motor (VCCDM) and SeaGoUt were very influential during the design of the module. The VCCDM (Fig. 2.3) is a module that controls the speed of a CD motor in order to alter its pitch, also controllable by CV. A pickup is used to amplify the sound of the CD motor [18]. The Gieskes SeaGoUt module (Fig. 2.4) outputs various signals, including clock by manually turning the module's wheel, which is taken from a hard drive motor. However, the hard drive motor does not rotate without being pushed manually [19].

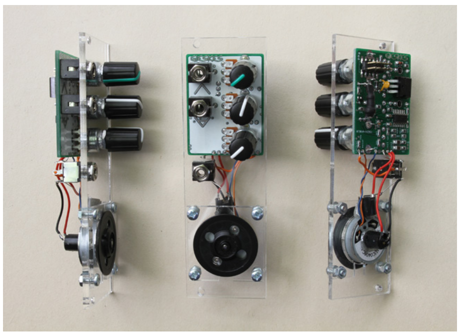


Figure 2.3: Gieskes' VCCDM Module [18]

Another highly influential product during the current project was the Monome Arc (Fig. 2.5). Brian Crabtree, founder of Monome, manufacturer of the influential 'Grid', details the Arc, which was designed to feature a "circular layout of steps

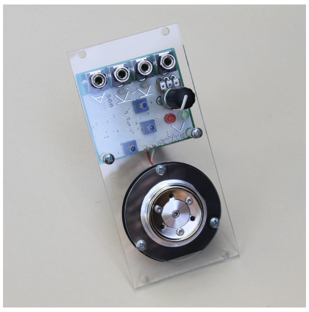


Figure 2.4: Gieskes' SeaGoUt Module [19]

and values", "The Arc explores circles, continuity and subtlety." "The four optical encoders (knobs) on the Arc are surrounded by a dense ring of lights" [5]. The lights provide the user with feedback about where in the circle each of the encoders are pointing.

Figure 2.5: Monome Arc connected to a Monome Ansible Module [20]

Bjorn discusses Bleep Labs' Thingamagoop 3000 (Fig. 2.6), "The Thingamagoops react to light; that particular feature might be highly meaningful and spark creative interest with some users, while others may find it uninteresting. The two-edged sword for manufacturers is catering to the mass-market on one side, potentially causing an instrument to be generic and boring, while on the other side, a unique approach to an interface risks misunderstanding and commercial failure" [5]. However, a complete system or device is more susceptible to this than an individual module that acts as a part of a larger system due to the number of different uses and possibilities for patching in the modular environment. Contextually, this gives more room for the module to suit the diverse practices of different users, allowing for the module to be used in many different and unexpected ways.

Two further examples of motors being used in DMIs are the Kyklophonon [22] and the Stepper Miniature [23]. Created by Sham Mas, the Kyklophonon (Fig. 2.7) is a DMI that uses a DC motor and various wheels, which function like gears, connected by elasticated rope threaded between one of the notches on each wheel. On each wheel there is a metal pick, which when rotated will pluck a string. The tuning of each of the strings can be altered and the instrument acts almost like a pitch-based sequencer for interacting with real-world strings.

Figure 2.6: Bleep Labs Thingamagoop 3000 [21]

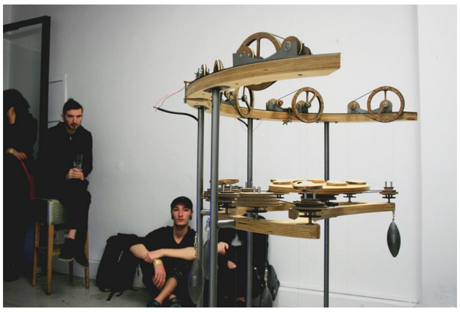


Figure 2.7: Kyklophonon [24]

The Stepper Miniature (Fig. 2.8), created by Koka Nikoladze, uses a stepper motor and piezos. The single octave keyboard produces the correct frequency for each of the keys by changing the speed that the stepper motor is rotating. A pickup is then used to amplify the signal. It is possible to generate octaves through the motor turning at half or double the speed. Vibrato and drum sounds through piezos are also included.

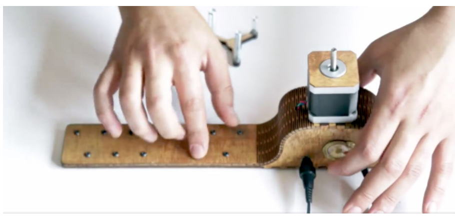


Figure 2.8: Koka's Stepper Miniature [25]

The relevance of these products is either through them reacting to light, featuring motors, rotating interfaces, or a combination of the two, or being related to modular synthesizers. While the Fan VCO discussed by and Gieskes' VCCDM and SeaGoOut modules, are quite similar, theoretically, to the module that the current project is based around, there are a number of key differences. One being that an initial inspiration and aim for the current device was for it to control tempo through a DC motor's wheel blocking the infared beam in a photointerrupter and thus generating clock speed (square wave LFO) based on the rotation speed of the motor. This clock speed can be then be sent to another module (such as a sequencer module) to set or modulate the speed at which it will playback. Whereas the Fan VCO is a voltage controlled oscillator meant specifically for audible range frequencies, rather than control of clock speed and thus only has an audio output limiting the module to CV input (no output). For example, a 20Hz square wave being sent to a sequencer would set the tempo as 1200 BPM, which is incredibly fast. 1200 BPM is also the upper limit of the LFO mode as above this the frequency starts to become audible rather than a series of clicks (waveform dependent). The Fan VCO is essentially a patch using a combination of modules rather than a more compact solution in a single module. The VCCDM amplifies the actual sound of the motor rather than creating synthesis based on the motor's speed and the SeaGoOut does not rotate on its own and must be moved manually in order for it to generate voltage (and therefore frequency) based on the speed of its rotation. Additionally, the Monome Arc is based around rotary encoders and momentum, the Thingamagoop 3000 does not feature a motor of any kind, the Stepper Miniature does have a DC motor and like the VCCDM amplifies the actual sound of the motor. Finally the Kyklophonon, does not synthesize sound but uses a motor in order to pluck strings at various pitches and at different speeds.

2.4 Summary

The current project will attempt to implement rotational speed as a representation of tempo and frequency, moreover the fact that tempo should be malleable and not static as is the case for a large quantity of contemporary electronic and more specifically dance music. The produced module will be an attempt to evaluate whether it is considered an engaging form of interaction for controlling tempo and frequency. Design requirements will be discussed in the 4 chapter.

Chapter 3

Review of Frameworks for Evaluating Digital Musical Interfaces

In this chapter, different types of evaluation frameworks, either related to, or specifically concerning digital musical interfaces (DMIs), will be discussed and assessed in order to design an appropriate combination of methods that will be used to evaluate the module this thesis is based on. Evaluation frameworks are infrastructures and experimental design principles, which outline how experiments should be carried out. Regarding DMIs, the evaluation process helps to identify successful elements of the device and uncovers shortcomings in specific areas of the device or the overall implementation. Although, as there are many different types of evaluation methods that are used for evaluating DMIs, a suitable one must be chosen in order to obtain the required feedback which can then be assessed, taken into account and used to improve the device.

3.1 Hybrid Luthierie

Many frameworks exist for evaluating digital musical interfaces. While most DMIs differ significantly in terms of design from those that are found in traditional lutherie (the practice of making stringed instruments), Armitage and colleagues use the methods for evaluating stringed instruments as a model for their evaluation. In order to focus on smaller, more specific details concerning the quality of a DMI and allow for more detailed comparison and evaluation. Concluding their review of existing frameworks, they argue that “it is important to consider what existing NIME frameworks might be missing, and what the consequences might be”. [26]. That is to ask, are the existing frameworks missing vital information, which could be gained through a different approach to evaluation. Comparing the existing frameworks for evaluating DMIs with that of evaluating a stringed instrument provides a much needed look at an established tradition for evaluating the quality of instruments. It also helps to ensure that the wealth of knowledge and experience from evaluations of lutherie is not ignored. There are many differences in terms of designing DMIs and traditional stringed instruments, and employing similar evaluation methods is quite a novel approach for evaluating DMIs. Employing this method of evaluation may reveal unique insights in comparison to more popular research methods within the community. This could help to further advance the success of future DMIs and make sure that there is some form of consistency between these two disciplines.

However, by directly comparing the evaluation of contemporary technologies in digital instrument making with that of such an established tradition as lutherie, one must ask, *do DMIs in fact need to be evaluated in an different way and on a entirely different set of criteria*? Although, by just assessing lutherie, which relates specifically to stringed instruments and not discussing traditions for evaluating other types of instruments such as brass, keyboard or woodwind, the authors do not claim this to be a comparison with all forms of traditional, acoustic instrument making and therefore this is maybe an area that could draw further advances in the evaluation of DMIs. Additionally, there is a recent trend emerging of hybrid luthierie such as the work of Romain Michon [27] and Otso Lähdeoja [28]. Hybrid luthierie is when electronics and sensors are added to acoustic or more traditional instruments in order to augment the sound creation possibilities of these instruments, or conversely DMIs (such as those developed for smartphones) are augmented with speaker cones to amplify the existing speakers present in the device. With these types of instruments, traditional lutherie and instrument creation evaluation methods are often considered, in addition to methods for the evaluation of DMIs. Also, this needs to be kept in mind throughout the design process, for example, adding large components to the body of an acoustic guitar will most likely change its resulting timbre.

3.2 Usability Testing

In Brown and colleagues [29] review of music interaction evaluations they notice a trend away from "task-based usability testing" and towards more "subjective and experiential based" NIME evaluation methods, which relate to User Experience (UX) evaluations in the domain of Human Computer Interaction (HCI) research. This method aims to gain insight into the "user's subjective experience of an interaction with technology". However, usability testing was found to still be the most common form of testing for performers (29.4%) in the study, this is partly due to the fact that it is closely related to "learnability and playability". These concepts are very important in order for a DMI to be both intuitive, and sustain longevity, which would allow virtuosic techniques to be developed over time. Performers were the most commonly used stakeholders (50.7%) in the 132 papers included in the study, which were all taken from the NIME, SMC and ICMC conferences between 2014-2016. Questionnaires (24.6%) were the most commonly used form of data collection in the surveyed papers. Brown, et al also observed that many evaluations "remain informal, and do not adhere to any particular method" and that "with a desire for generalisable results, the NIME community would benefit from evaluations following established methods" [29].

Usability testing aims to assess what is successful and what can be improved in terms of user interfaces. Flaws in an interface can be defined as a component of the interface that may be confusing, misleading or generally sub-optimal, and causes problems for a majority of people [30]. An example of qualitative usability testing data, using interviews to investigate usability for a DMI being used can be seen here: [31].

3.3 Physiological Measurements

Think-aloud evaluations concern performing tasks and asking the user to provide feedback in real-time. Participants are asked to discuss and describe their actions verbally during interaction with a system, however this can be intrusive and affect either how the user interacts with the system by limiting their level of engagement, creative flow, or the responses they provide. This prompts O'Modhrain, in her review of frameworks for evaluating DMIs, to ask, "Is it possible to devise a methodology that could capture a player's experience of playing while they are engaged in a musical task?" [32]. One solution to this could be the use of physiological data collection methods such as electroencephalograms (EEG), electromyograms (EMG) or galvanic skin response (GSR). These methods are still relatively unexplored territory in terms of evaluating DMIs and have mostly been used for audience evaluations, i.e. not the performer. These methods allow data to be collected in real-time, which reduces the "peak-end effect" [33], which will be discussed further in the next section. One problem with many frameworks is that they do not capture responses or data about given tasks at the same time as they are taking place, and therefore may not be an accurate depiction of the participant's opinion due to the possibility of being influenced by other factors before giving their responses.

As O'Modhrain [32] discusses, "While physiological tracking has already been employed as an input method for musical control [...], it does not yet appear to have been used directly to evaluate the experience of playing a DMI." While O'Modhrain [32] describes these techniques as "non-intrusive systems", apparatus needed to acquire such physiological data, could be seen as quite intrusive by some users. For example, the cap and gel that the user must wear while gathering data from EEGs.

The GSR sensors used in [33] were attached to the users' non-dominant hand. "This was done so that participants would not be impeded during interaction with the system as the GSR readings were sensitive to hand movements." In fact, the researchers removed the data for two participants from the results due to noise from hand movements."Such artefacts were typically caused by participants moving their hand with the GSR sensor attached." Wristband sensors are commonly used to collect GSR data. If these were used they would most likely be intrusive as the participant would have to interact with the DMI using one hand as GSR apparatus generally require one hand to remain rested in order to obtain accurate data. Forcing the participant to interact with a device using only one hand (when their natural instinct would be to use two) could be intrusive and consequently, could affect the participant's actions and or creative flow during the experiment. This fact makes gathering GSR data during performances using DMIs challenging. Physiological data is used, largely, in DMI evaluations for audiences. There are many different types of GSR sensors however and attaching a sensor to another body part with a large number of sweat glands such as the sole of the foot "600 to 700 glands/cm^2" [34] may be of use in DMI evaluations that largely require interaction to be done using the fingers/hands.

3.4 Use of Video and Video-cued Recall

Brown and colleagues [29] also identify other emerging forms of participant tasks such as "Watch Performance - Participants watch a performance given by a musician, in either a concert or laboratory setting (e.g. watching a video)" and data collection methods "Audio/Video Recording - Recordings of experiment are used in the analysis" [29]. The combination of which essentially forms the basis of video-cued recall. Largely this has been used for audience evaluations of performances using DMIs, but has previously been used to assess user interaction with other types of systems. Currently, this has mostly has been used for audience evaluations such as [35] and non-DMI related user experience UX experiments [33], where physiological measurements were also taken, but only one hand was used to interact with the system (controlling a mouse). A use of video-cued recall as an evaluation for an art installations with a collaborative element (that could be considered a DMI due to its interactive audio-visual) can be seen in: [36].

In Bruun, et al's study, quantitative data was gathered from GSR and subjective self-assessment manikin (SAM) ratings. Qualitative data was gathered through cued-recall with the selected participants viewing video clips of their interaction. The GSR sensors were also worn by the participants while viewing the video, this allowed them to compare GSR data between the actual interaction and the video cued-recall for their correlation and intensity hypotheses. For the selected participants, where video cued-recall was used they played video clips from each GSR peak from the interaction and "asked to comment on what they felt and were thinking during the event shown in the clip" [33].

One issue with using data collection methods that are required to be completed after interaction with a system is that they are susceptible to memory bias. Specifically the "peak-end effect", which concerns a participant's retrospective free-recall responses about an interaction during an evaluation and tend to highlight the "most intense and final emotions of an event" rather than the interaction with the system as a whole. Conversely, if the method requires interrupting the interaction, this risks affecting the participant's perception of the task(s) and/or system as a whole. While as Bruun discusses, "HCI researchers and practitioners now have cued-recall as an alternative that significantly reduces the memory bias and enables highly detailed measurements of emotions while not disturbing participants during system interaction" [33].

However, real-time data collection does have the limitation that quantitative data is far easier to obtain, and as Bruun notes, "we need qualitative insights in order to make relevant changes to a particular interaction design." Obtaining qualitative data in real-time is difficult and risks intervening with a participant's behaviour during an experiment [33]. One alternative to using free-recall is to use video cued-recall, this uses clips of video recorded during the experiment to prompt participant's memories of notable interactions.

3.4.1 System Usability Scale - List of Statements and Usage

Using SUS consists of presenting the participant with ten statements, after they have completed the both the tasks set during the experiment and unstructured use of the device. The participant then rates how much they agree with the statement on a five-point likert scale (1 - strongly disagree, 5 - strongly agree). The intention of completing the tasks is for the user to cover all the different modes and functions of a system in order to give a fully informed opinion. The order of the presented statements alternates between positive and negative, of which there are five of each, excluding the additional final question, which is rated by the user on a seven-point adjective likert scale (1 - Worst Imaginable, 2 - Awful, 3 - Poor, 4 - OK, 5 - Good, 6 - Excellent, 7 - Best Imaginable) [37]. In addition to the standardized questions below, device specific questions will also be asked in order to obtain feedback about interaction with specific modes or parts of the interface.

The same adjectives from the eleventh statement above, used to describe user-friendliness, can be correlated with the mean SUS scores for the product and compared. How these relate to the numerical SUS scores, and other scales of grading and acceptability, can be seen in Fig. 3.1.

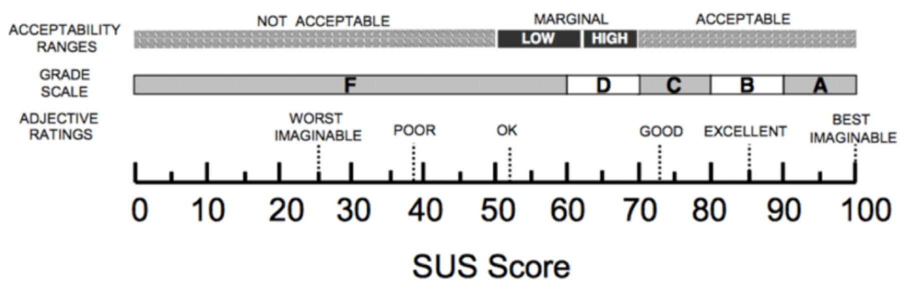


Figure 3.1: Comparison of Average SUS Scores with Adjective Ratings, Acceptability Scores, and school grading scales. [37]

The SUS score is calculated through each of the participants responses to the statements above being summed. The score contribution for the positive statements (1,3,5,7,and 9), is the scale position minus 1, and for the negative statements (2,4,6,8 and 10) is 5 minus the scale position. The sum of then scores is the multiplied by 2.5 to obtain the overall value of system usability for each user. The mean of these scores is then taken to give an overall SUS score. SUS scores have a range of 0 to 100, however this number is not to be considered as a percentage [38]. An example of use of the system usability scale for a DMI can be seen here: [39].

In summary, a System Usability Scale will be used to gather quantitative data about the system as a whole. Additional questions regarding specific features, interactions and improvisation with the system will also be asked on a 5-point, positive statement likert scale to gather more in-depth data. Both of the above will gather quantitative data about the system, while video will be recorded during the experiment to gather real-time data. Selected clips will then be played back to the participant, who will be asked to comment on their interactions during each clip. This will facilitate the gathering of qualitative data (thus, a mixed method will be used) and allows memory bias and the peak-end effect to be reduced, while concurrently obtaining qualitative data.

Chapter 4

Implementation and Iterations

4.1 Overview of Module Design and Influencing Factors

This chapter will detail the iterative design process and various stages of implementation. The name of the module - *Motorique* is a portmanteau of the words *boutique*, often used as a word to describe smaller scale Modular synthesizer companies with a DIY approach and the word *motor* as the module is based around the relationship between the speed of the motor (input) and frequency (output). Another reason for the choice of this name is that when pronounced, it sounds very similar to Motorik (itself a portmanteau of motor, and musik), the name given to the 4/4 rhythm pattern used by many Krautrock bands such as Can, Kraftwerk and Neu![1]

The design of the module was heavily influenced by turntables and DJ culture (in addition to tape machines). The resulting final iteration has a similar appearance to the DJ setup used in most clubs (albeit rotated 90 degrees), with two turntables and a mixer with potentiometers for controlling various parameters and effects in the centre of the two. Making the size of the device as compact as possible without affecting and usability of the device and possible interactions was important for ensuring that the target group would still want to include the module in their modular systems. The amount of space that any single module has in a rack is often a large concern for Eurorack users as space is at a premium. Some of the more popular modules with larger widths are shrunk down to smaller footprint DIY modules in order to accommodate this.

The basic design can be described as two motors, which individually set frequency for each oscillator, whether it be low frequency (LFO) or audible rate (VCO) oscillators through the use of an optical sensor, motor wheel encoder and hardware interrupts in order to calculate the revolutions per minute (RPM) of the motor. This would then be mapped linearly to the frequency, such that a faster RPM would set a

[1] Krautrock was influential in the popularisation of synthesizers in popular music and also laid some of the foundations for electronic music genres such as Techno. These groups used many different synthesizers, but some of the more notable were modular synthesizers such as the Moog Modular, in addition to other technologies such as tape machine experimentation and effects processing.

higher frequency. Moreover, if a square or pulse wave was used for the LFO and this was patched to an external module in such a way that it was triggering the tempo of a drum beat or sequence of notes, the resulting tempo could be modulated by changing the speed of the motor and a rotating, visual representation of the tempo could be obtained by the user. It was also decided that for the frequency modulation (FM) mode, the motor would control the rate of modulation rather than the carrier frequency.

4.2 Motorique Design Requirements

1. The revolutions per minute (RPM) of the module should be perceptually linked to the resulting frequency or clock speed sent to other modules. Specifically, setting a faster RPM would equal a higher resulting frequency or faster tempo and this interaction should be engaging for the user.

2. The user should be able to create a sound or timbre they find engaging or pleasing through combination, improvisation and interaction with the various controls and modes available, after the user has been given an explanation of the system.

3. The module should be capable of sending control voltage (CV) signals to other modular devices for control or modulation of tempo or frequency.

4. The module should provide a variety of different modes for use with the internal sound engine and interfacing/controlling other modules in order for it to be considered a utility module.

5. Each of the oscillators should be switchable in terms of mode (LFO, VCO or FM), such that they could be used individually as an audio (internal/standalone) or CV output (for controlling other modules). For example, one oscillator could be used to send clock speed to control the tempo of a drum beat, while the other oscillator could be used for setting the rate of modulation for FM (internally or for modulating an external module with the LFO or VCO), or for setting the frequency of the internal VCO.

4.3 Proof of Concept Iteration - Modular Patch

As a proof of concept, a modular patch was created (Fig. 4.1) using a combination of three Bastl modules, the DC Motor, Sense, Little Nerd and two Gieskes modules - the SeaGoUt and the VCCDM. The wheel of the SeaGoOut is spun which sends CV signals to the VCCDM CV input (VCO Fan module used in place of this in Fig. 4.1 due to unavailability of module in Modular Grid). the VCCDM audio output is then sent to a mixer so it can be heard, the SeaGoOut modulates the speed of the VCCDM set by the potentiometer. The SeaGoOut was also patched to the Little

Nerd in order to use its various functions (for example, the clock divider) to process the CV signals before being patched to the CV input of the DC Motor module, which consequently sets or modulates the speed of the DC Motor attached to the module. The Sense could also have been used to connect a light dependent resistor (also known as an LDR or photocell) and LED. With the motor placed in between the two (and something attached to it, blocking the path of light between the LDR and LED), the Sense would have created a CV signal that could be send to the VCCDM (or other modules) to set or modulate its frequency, which could be altered by changing the speed of the DC Motor.

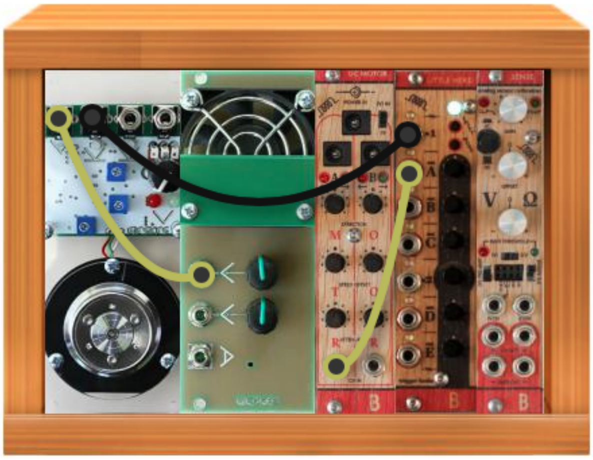


Figure 4.1: Proof of Concept Modular Patch.

4.4 Electronics and Iterations

4.4.1 DC Motor Controller and Photo Sensor Iterations

L293D Motor Driver and Light Dependent Resistor Iteration

The original schematic for Bastl's DC Motor module from Vaclav Pelousek's Master's thesis [17] and the updated module itself were inspected in order to deduce how this module controlled the speed and direction of the DC motors. A similar prototype was then made (Fig. 4.2).

The initial prototype included the use of the H-Bridge L293D motor driver IC and various components present in the OMSynth (Fig. 4.2). The motor speed is controlled through Pulse Width Modulation (PWM), which works by varying the duty cycle of a pulse wave (a square wave at 50%, Fig. 4.3). A piece of Arduino code was written to control the motor speed through a potentiometer, a light dependent resistor (LDR) was then used to set the frequency of one of the oscillators of the hex inverter (CD40106), in combination with the OMSynth for control and audio output (Fig. [40]).

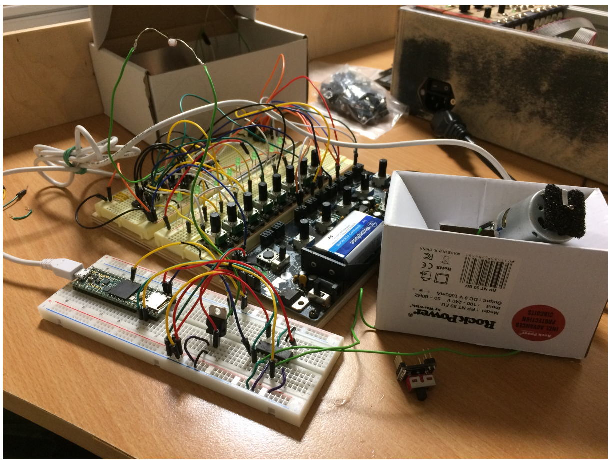


Figure 4.2: First DC Motor Driver Implementation.

However, one problem with this setup was that the speed of the DC motor used was far too high, even when the speed control was set to its minimum. Another issue with the DC motor and using the L293D in general was the high amount of current that was required, to start the motor running at lower speeds from a stalled state it would need to be spun manually, which would not be very intuitive for the user. For the aesthetically desired revolutions per minute to be attained (a maximum of 45 RPM, as with record players, excluding the archaic 78RPM format), a geared DC motor would most likely be needed. Another issue was that the LDRs are analog and not digital sensors, and thus less suitable for use with hardware interrupts for RPM detection.

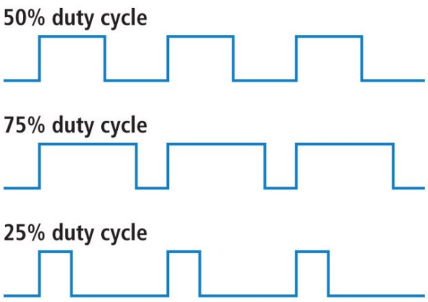


Figure 4.3: 50%, 75% & 25% Pulse Width Modulation Duty Cycle [41].

While the directional rotation of the motor was used in this iteration, it did not alter the way in which the system functioned whatsoever. For this, two offset light sensors would be required in addition to a quadrature encoder attached to the motor wheel. This was not implemented in either of the iterations tested in the final experiment. However, due to their analog nature, providing continuous data, LDRs are susceptible to variations in sensitivity and functionality due to ambient lighting.

LM358N Based Motor Driver and Reflective Object Sensor Iteration

In order to address the issues with driving the DC motor speed at the lower speeds required, a custom motor driver was built with help from Archelaos Vasileiou [42] (Fig. 4.4), who designed the circuit. It is based around the LM358N dual operational amplifier and similar to the L293D iteration discussed above, controls motor speed through modulating the width of a pulse wave (PWM - Fig. 4.3) and its duty cycle. The use of this motor driver reduced the amount of torque required to start the motor, making it far more usable in a DMI for interacting with other modules, especially for the slow RPM desired. The circuit provides PWM control of the motor speed. A geared motor was also used for this iteration, with a maximum revolutions per minute (RPM) of 45. This was an aesthetic choice based on the the playback speed of most vinyl singles (7” & 12”). It was used in order for the user of the module to be more familiar with the speed of rotation as many users of modular synthesizers will already be used to playing vinyl records or DJing.

If this motor was used and an RPM to Hertz (hz - frequency) ratio of 1:1 was implemented, the maximum frequency of the oscillator would be 45hz (only 25hz above the lower limit of audible perception for most humans), essentially limiting the voltage controlled oscillator (VCO) mode of the module to a range of 25hz, which would be very limited in terms of frequency range. Therefore mapping would need to be done in software for the different modes. A brushless DC motor would also be likely be needed for a product that went to market in order to ensure the longevity in terms of usage of the motors in the module, however this would come at a significantly increased cost for production.

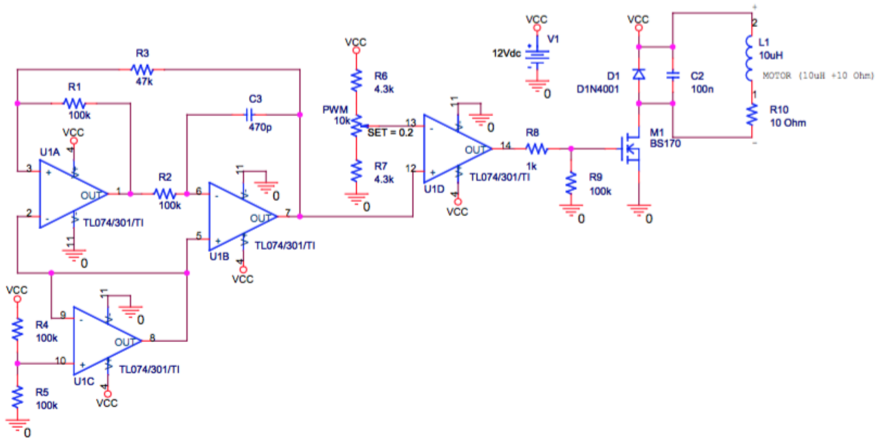


Figure 4.4: LM358N Based Motor Driver. [42]

OPB745 reflective object sensors/photo darlington interrupters were used in the iterations for testing. Its working properties also allowed the component to fit easily into the panel (right next to the motor) without in anyway obstructing the user’s interaction with the motor wheel. The component works by having an infrared (IR - thus avoiding the effect of the visible light spectrum and varying ambient light conditions) LED and photo darlington directly adjacent and angled towards each other, such that it can detect how reflective an object or surface is. While the range is relatively small (maximum distance = 3.8mm), the component was used due to ready availability and the possibility to avoid interfering or influencing the user's perception of the mapping to frequency by having a component (or part of a component) above the motor wheel encoder. Their digital nature and compact size were also contributing factors in the decision to use them.

Alternative components considered were separate IR photo diodes and IR LEDs, this would require the IR LED or photo diode or transistor to be placed either side of the holes in the motor wheel encoder, most likely above the panel (similar to Bleep Labs' Thingamagoop 3000 in Fig. 2.6), or encapsulated photo interrupters (composed of aligned IR LEDs and photo diodes or transistors), where the motor wheel encoder would need to be placed between the gap separating the IR LED and photo sensor in order to trigger hardware interrupts in software. Due to their generally faster switching times and reduced noise, this would have minimised latency issues in the RPM detection, thus improving the possible speed for modulation of frequency that was output to audio or CV (as noted by some participants during the experiment 6). A decision was made to continue using the OPB745s due to the lateness of this realisation in terms of the timespan of the project. The implications of changing the already completed design at this stage were impractical, especially as this was after the evaluation of the first iteration had been completed and other improvements had been planned for the few hours between testing each iteration that were more plausible than changing the whole design of the module.

4.4.2 CV Output and Power

Both the CV output and power (provided from the standard Eurorack bus board) sections of the module were heavily inspired by the schematic for the open source Eurorack module, Ornament & Crime [43], which has many different functionalities and applications available in its firmware.

An operational amplifier (op amp - LM358) was used to amplify the signals for increased range of CV control. That is, after testing that 0-3.3v from the Teensy DACs worked for this purpose. The resistor values for the CV output as outlined in [44], for a CV range of -3v/+6v were adjusted through changing the resistor values in the op amp circuit to approximately achieve the -/+4v CV range for the Plankton Ants that will be used in the experiment. This can be seen in the final schematic in Appendix B.

The power was a main issue that forced the parts of the module to be used on breadboards and supplied with -/+12v from a DC power supply. An intended final iteration was produced on stripboard for permanisation of the design and electronics, however when the circuit was connected to the power supply, the Teensy would instantly turn off. Grounding issues could also have caused this issue, but at the late stage that the issue was discovered, it was decided that rather than debug the circuit, which could have taken a significant amount of time, it was more beneficial to use parts of the circuit that had already been tested and confirmed as functioning correctly on breadboards by the author during the experiment. This part was omitted from the final Eagle schematic (Appendix B) due to its exclusion from the experiment, but it would be almost identical (possible removal of capacitors) to [43] when it is implemented.

-/+12v was used for the LM358 power to obtain the correct CV output, with an LM7806 6v voltage regulator then used for the motor driver op amp circuits to ensure maximum 45RPM motor speed. 3.3v was used for all potentiometers (excluding RPM), reflective object sensors and voltage references for the CV output op amp circuits.

4.5 Microprocessor, Software and Teensy Audio Library

After a proof of concept iteration was completed using the Arduino DUE, due to its two DACs (Digital to Analog Converters) for dual mono audio and CV output. Components used included LDRs for setting the oscillator frequency and the Arduino Function Generator code [45].

The Teensy 3.6 was used for the final iteration due to its fast processor and dual on-board DACs (Digital to Analog Converters), making it suitable for use in a Eurorack Module. The smaller footprint of the Teensy when compared with many other well known microprocessors (Arduino, BeagleBone, Bela, etc.) was another consideration made during the design process.

Another useful feature of the Teensy, is the Teensy Audio Library and Audio Design Tool, allowing for fast initial implementations of the system and various modes. Code was then written in the Arduino IDE in order to map and connect the various components used for interaction with the module and navigation through the various options within the system. The mapping was done as follows: 0-45 RPM mapped to 0-20hz for LFO; 20-10000hz for sine wave VCO, with 20-1000hz mapped for other VCO waveforms; and 0-1000hz mapped to both the carrier and modulating frequencies of the FM mode for more extreme brassy timbres at the higher end of modulation. All mappings were linear for both iterations used in testing.

The Volt per Octave (V/Oct) mode was used in iteration 1, but due to its incorrect functionality during testing of iteration 1, it was replaced by a more limited tempo mapped (maximum = 300 BPM) LFO for triggering sequences in iteration 2. Initially the V/Oct mode was mapped such that 0 RPM would send approximately -4v and 45 RPM would send approximately +4v, enabling eight octaves of frequency to be set for external oscillators (this mode would need to be revised for a final version to ensure correct functionality).

Many voltage ranges exist for modular synthesizers, but the range of +/-4v was chosen due to the limits of the Plankton Ants semi-modular synthesizer that would be used during testing. A feedback delay was also added with variable delay speed (removed in iteration 2 due to audio issues) and feedback amount. This overall, gave the module more explorability for both the internal modes and for using experimental delays for CV signals send to other modules; for example, using delay on LFOs to send frequency modulation and clock signals to external modules in interesting ways.

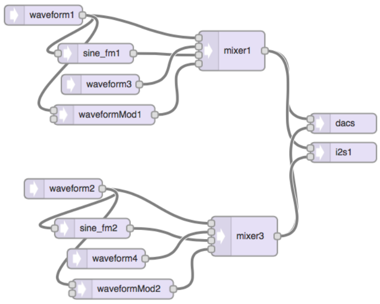


Figure 4.5: Teensy Audio Design Tool and Initial Design.

The four modes of the Motorique are individually selectable for use with each of the two sets of controls (detailed further in Fig. 4.6 and Fig. 4.7). The controls include the DC motor wheel, potentiometers and switches. The modes are as follows:

1. LFO (with Switchable Waveforms).
2. VCO (with Switchable Waveforms).
3. Frequency Modulation (FM) Synthesis (with Dual Switchable Waveforms).
4. Volts per Octave (Iteration 1)/Tempo Mapped LFO (Iteration 2).

4.6 Iterations used for Initial Feedback and use in Final Experiment

4.6.1 Panel Design

Paper Prototype

A paper prototype (Fig. 4.8) was made part way through the project and sent digitally to distribution assistant/workshop coordinator at Bastl Instruments, John Dinger. This was done after regular, informal discussions in person. John Dinger (John Dee) also regularly performs live with modular synthesizers.

It was agreed that, while he really liked the use of slide potentiometers as they provide instant visual feedback about continuous variables, if the the motor was going to be used as the main method for setting frequency, the motor wheels could be made more prominent in the design (in addition to making the whole design wider than 12hp). A suggested solution was to use standard potentiometers and

Buttons				
	Button 1 - Waveform	Button 2 - Mode	Button 3 - FM Waveform	
LFO	Waveform	VCO	N/A	
VCO	Waveform	FM	N/A	
FM	Modulating Waveform	V/OCT	Carrier Waveform	
V/OCT	N/A	LFO	N/A	
Knobs				
	Knob 1 - FM Frequency	Knob 2 - FM Amount	Knob 3 - Delay Time	Knob 4 - Delay Feedback
LFO	N/A	N/A	Delay Time	Delay Feedback
VCO	N/A	N/A	Delay Time	Delay Feedback
FM	Carrier Frequency	FM Octaves Amount	Delay Time	Delay Feedback
V/OCT	N/A	N/A	Delay Time	Delay Feedback
Motor Speed				
	Function			
LFO	Frequency			
VCO	Frequency			
FM	Modulating Frequency			
V/OCT	Frequency (only when sent to other modules)			

Figure 4.6: Iteration 1 - Function of Controls for each Mode.

buttons rather than switches in order to maximise the amount of space available for larger motor wheel. Also, it was agreed that the slide potentiometers could make it easier to accidentally touch the motor wheel affecting frequency or tempo due to their size. These suggestions were fully acknowledged and implemented in the final design. Obtaining an expert's opinion (10+ years of experience playing modular synthesizers and working in the industry) on the overall design and functionality gave added validity to the changes made for the final iterations.

Final Design Iteration

Adobe Illustrator was used for design of the module, with Corel Draw used for minor adjustments before being sent to the laser cutter with optimised settings. The panel was cut from 3mm MDF (as influenced by Bastl Instruments Eurorack Modules), whereas the wheels were cut from 3mm white acrylic in order to maximise reflectivity. The final design for the module can be seen in Fig. 4.9 and Fig. 4.10 below.

No slide potentiometers were used in the final iterations as discussed above and switches were replaced with buttons. Eight potentiometers were used for various parameter controls (Fig.4.6 and 4.7). Another standard potentiometer was used for setting motor speed in order to gain more space in the design for the motor wheels. Six buttons were used rather than the four switches in the paper prototype due to their suitability for switching between waveforms and modes. Typically, switches would be better suited to on/off than those with multiple options for each button. Again, this increased the possible space for increasing the size of the motor wheels.

Other changes made to the final iteration included: larger engraved text was included on the panel to ease the learning curve for new users; larger motor wheel

Buttons				
	Button 1/4 - Waveform	**Button 2/5 - Mode**	**Button 3/6 - FM Waveform**	
LFO	Waveform	VCO	N/A	
VCO	Waveform	FM	N/A	
FM	Modulating Waveform	Tempo Mapped LFO	Carrier Waveform	
Tempo Mapped LFO	Waveform (Only Square or Pulse)	LFO	N/A	
	in order to function as intended			
Knobs				
	Knob 1 - FM Frequency	**Knob 2 - FM Amount**	**Knob 3 - Delay Time**	**Knob 4 - Delay Feedback**
LFO	N/A	N/A	Delay Time	Delay Feedback
VCO	N/A	N/A	Delay Time	Delay Feedback
FM	Carrier Frequency	FM Octaves Amount	Delay Time	Delay Feedback
Tempo Mapped LFO	N/A	N/A	Delay Time	Delay Feedback
Motor Speed				
	Function			
LFO	Frequency			
VCO	Frequency			
FM	Modulating Frequency			
Tempo Mapped LFO	Clock Speed			

Figure 4.7: Iteration 2 - Function of Controls for each Mode.

encoder holes in an attempt to reduce the number of missing interrupts and cuts in the panel for the reflective object sensors were also rotated 90 to optimise space for components beneath the panel.

4.6.2 Prototype for use in Experiment - Iteration 1

Due to time constraints and the focus of the project, bandwidth limited waveforms were not implemented. But waveforms with a higher amount of frequency partials other than a sine wave were limited from 20-1000hz (0-20 hz for the LFO) and a resistor/capacitor filter was added between the Teensy DAC outputs and LM358 in order to reduce the effects of aliasing as much as possible.

4.6.3 Prototype for use in Experiment - Iteration 2

Changes from Iteration 1

1. As it was discovered in iteration 1, the OPB745 was missing multiple interrupts. In an attempt to solve this issue between each iterations for testing, a spacer was attached between the motor wheel and the motor shaft (Fig. 4.11). It was also possible to straighten the motor wheels and make them far more stable than in iteration 1, due to the increased space between panel and wheel. Again, this was done to avoid missing hardware interrupts.

2. The delay time was removed as a user controlled effect due to the glitches it was causing with the audio. These were known, prior to the test of iteration 1, and due to time constraints a fixed delay time of 400ms was used. However, potentiometer control of delay time, one of the tools available for possibly new techniques to be developed by users (modulation of delay time with other functions of the module), was removed.

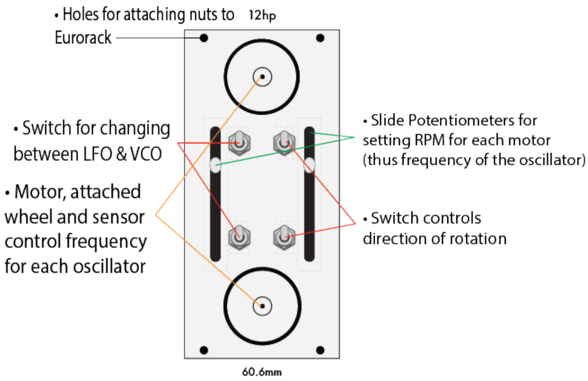


Figure 4.8: Paper prototype.

3. As during testing iteration 1, it was found that the V/Oct mode was not functioning correctly, the LFO was used as a source of modulation for CV control of external oscillators (FM). These improvements may have influenced participants to use the module in new interesting ways. For example, patching FM mode to an external oscillator for multiple levels of frequency modulation, possibly increasing the level of experimentation and improvisation possible.

4. The V/Oct mode was replaced with a tempo mapped LFO for a smaller range of tempo, 0-5hz, resulting in a range of 0-300 BPM. However, users could still use the full frequency LFO for a wider range of tempo (0-20hz or 0-1200 BPM) if desired.

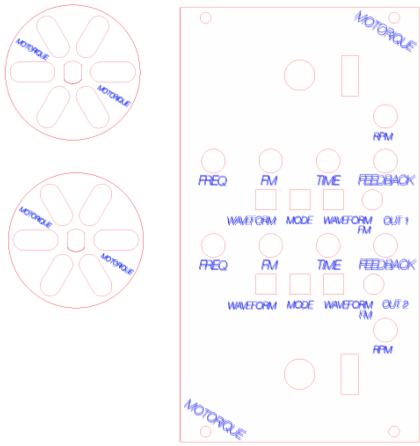


Figure 4.9: Final Laser Cut Design.

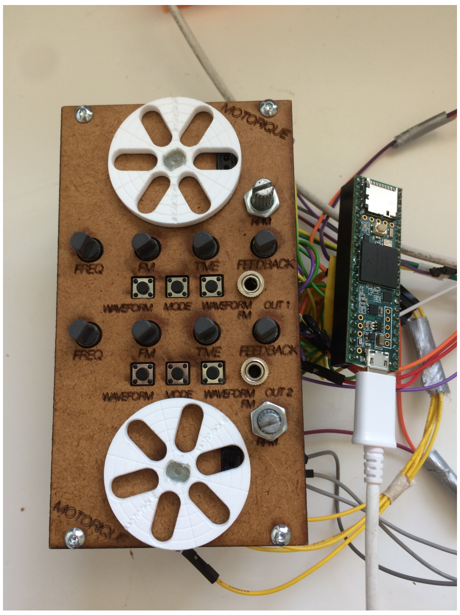


Figure 4.10: Final Design.

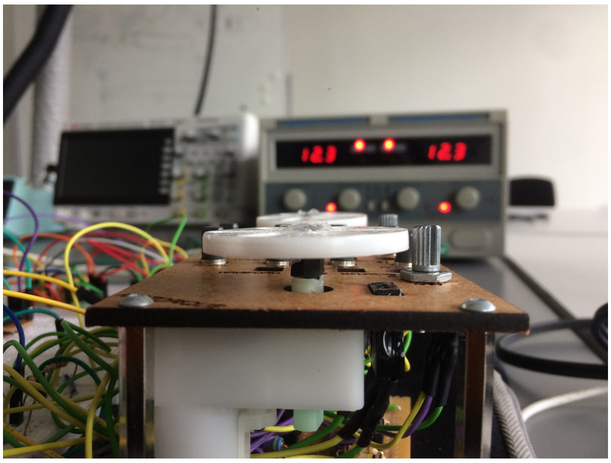


Figure 4.11: Raised Motor Wheel.

Chapter 5

Evaluation and Experimental Design

This chapter describes the process of testing and evaluating Motorique with users. A combination of real and non-real time were used. Also, the results will be analysed and compared with design requirements in order to determine how successful each iteration was.

The current project will employ usability testing in combination with video cued-recall. By combining the use of usability testing, a popular methodological framework for evaluating DMIs with a relatively unused method for DMIs (video cued-recall), an established non real-time data collection method will be employed in addition to video cued-recall, which will add a new dimension and enable real time data to be collected. Consequently, both quantitative and qualitative data will be obtained and data regarding interaction, emotion, improvisation and usability. Thus, a mixed method will be used. The above methods will be detailed further, later in the chapter, after the planning of the experiment, equipment and software, set tasks (internal and external) and unstructured use are detailed below.

5.1 System Usability Scale - Planning of Experiment

Below, the main steps for planning system usability scale (SUS) testing are outlined.

Stages of Usability Testing Model [30]

1. Select representative users - 1. Active or occasional users of modular synthesizers (hardware including semi-modular synthesizers and software such as Max, PureData, Reaktor, Softube, VCV Rack, VSTs, etc). 2. Students studying Sound, Music or Computing related subjects, or graduates of these studies. 3. Active or occasional users, preferably, of hardware synthesizers, but also software such as DAWs and apps.

Any participants with experience of playing an instrument, composing or performing music or studying sound or music related subjects for more than ten years in total were considered musical experts in general, however this may not apply to modular synthesizers. Convenience sampling will be used to recruit participants who are readily available at the time of different iterations being ready to test.

2. Select the setting - Electronics Lab at Aalborg University Copenhagen 5.1.
3. Decide what tasks users should perform - Detailed in Set Tasks and Unstructured Use subsection below.
4. Decide what type of data to collect - Mixed method with quantitative, usability testing for the overall system and likert scale for specific features of the device, and qualitative data gathered through the use of video-cued recall. Participants were encouraged to discuss their interactions and emotional responses to four specific clips of themselves using the device, directly after watching each clip.
5. Before the test session - Informed consent (see appendix A).
6. Debriefing after the session - Extra comments and suggestions for improvements welcomed.

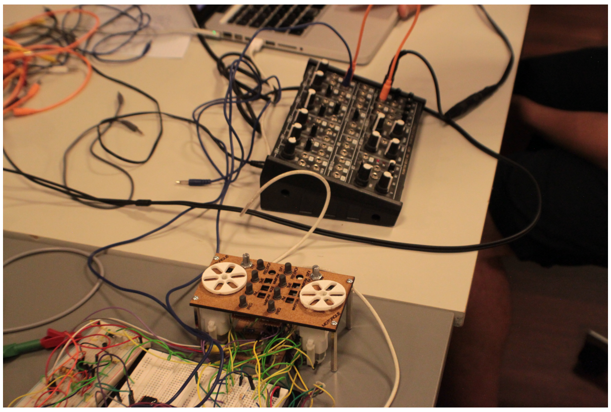


Figure 5.1: Lab setup for testing of module (Iteration 1 with lower wheel).

5.1.1 Pilot Test

A pilot test was done with one participant in order to gain information about the total amount of time taken for the experiment. The only changes made to the final experiment were technical issues such as the realisation that the Canon 500D stops recording automatically due to overheating after approximately twenty minutes if High Definition (HD - 720p and 1080p) video is recorded. Using Standard Definition video (SD - 480p) was used to to solve this issue. Also the offset between the start of the video and audio recordings were not noted, making synchronised playback of the selected clips far more difficult and possibly affecting the participant's responses. As a solution to this issue, the offset between the start of the audio and video was noted at the start so correct time codes could be found with less difficulty and with the correct synchronisation.

If more time was available, further pilot testing would have been carried out, however the only issue that occurred during the final experiment was out of the researcher's control due to two of the participants having imminent Master's thesis deadlines. Both of these participants asked if the test could be completed in the minimum possible time for the experiment, however they were still encouraged and did perform improvisation and unstructured usage of the device and performed all set tasks and answered all set questions. It is important to consider the needs and wellbeing of research participants, for their own sake and also to ensure data quality. Thus, they were not excluded from the results and analysis.

Another minor issue was that the research was undertaken by a sole researcher; hence video and audio recording, explanation of the modes and controls to the participant, re-patching for setting the module up for control of the Ants (external synthesizer), resetting of the Ants drum patch between tests, noting time codes of selected clips for video-cued recall and ensuring everything was functioning as intended were all undertaken by one person. If this experiment was to be repeated, a research assistant would be used in order to reduce stress and the number of tasks necessary for each person conducting the testing.

5.1.2 Equipment and Software Used During Experiment

Equipment

1. MacBook Pro (13-inch, Mid 2010 with SSD and 16GB RAM) - Used for powering Teensy and displaying various information during the experiment (detailed in Fig. 4.6 and 4.7).

2. Canon 500D and Tripod - 480p video recorded due to overheating issues with high definition video recording.

3. USB SD Card Reader.

4. Sennheiser HD600 Headphones.

5. DC Power Supply.

6. Oscilloscope - Only for researcher's reference, as no speakers were used (participants asked not to pay attention to it).

7. Plankton Ants Semi Modular Synthesizer.

8. 2 x Breadboard.

Software

1. Quicktime - Internal audio recording (Ants audio not recorded in an attempt to keep the participant focused on Motorique and not the sound of the external device being controlled); internal audio of module for participant (audio still embedded and produced by the Teensy, MacBook just acting as a USB audio interface); and playback of clips for Video Cued Recall.

2. Arduino IDE - Displaying mode and button visual feedback on the serial monitor.

3. Preview - Displaying relevant system information (Fig. 4.6 and 4.7).

4. Safari - Google Forms used for data collection.

5.2 Set Tasks

5.2.1 Internal Modes and Audio of Module

The participants will be encouraged, after explanation, to interact with the various controls (including motor wheel, potentiometers and buttons) for each of the embedded (internal audio) modes of the Motorique module:

1. LFO - Briefly to get a basic idea of how the RPM is coupled with frequency, in this mode using the internal audio, just a series of clicks would be heard by the participant (Square wave).

2. VCO - All available parameters (Fig.4.6 and 4.7).

3. FM synthesis - All available parameters (Fig.4.6 and 4.7).

Participants were able to view a spreadsheet of the different functions of the buttons, potentiometers (knobs) and motors for each mode during the experiment. This was corrected for the changes between each iteration. Additional information was provided including known issues with the device, such as the fact that the motor needs to be running in order to set frequency (otherwise an arbitrary frequency would be set, not relating to the stalled nature of the motor).

5.2.2 External Modes of the Module for interfacing with Plankton Ants Semi Modular Synthesizer

The Motorique module was then patched for the user to interact with the Plankton Ants Semi Modular Synthesizer in the following ways: Improvise with controls, repatch (could also explain or re-patch for the user) but mostly keep focus on using the Motorique as an interface. Also, the participant was informed of limitations when using the Ants (outputs should not be patched to outputs - white boxes around label), and when controlled by the Motorique, for example if the Ants' oscillator frequency was close to either the very high or low end of the range, CV control would be limited and not as apparent due to the nature of CV. The various modes of Motorique are detailed below:

1. LFO - In iteration 1 this was used to send clock signals (square or pulse waveforms only) to the Ants, where a pre-patched drum beat (Fig. 5.2) had been set up, the clock speed modulates (coupled to the motor speed) the tempo of the drum beat. In iteration 2, this mode was instead used for interfacing with the Ants for FM of one of the oscillators due to incorrect functionality of the Volts per Octave mode for some of the participants.

2. Volts per Octave (iteration 1 only, removed for iteration 2)/Tempo mapped LFO (iteration 2 only) for drum beat tempo (Fig. 5.2) much in the same way as above but with a more limited tempo range.

3. FM - In Iteration 2, this mode was also offered to users for further experimentation and used for interfacing with the Ants for FM with further experimentation with modulation options.

4. FM and tempo mapped LFO - In Iteration 2, the participant was offered the opportunity to have one of the motor speeds affecting the speed of the drum beat and one of the motor speeds modulating the frequency of one of the Ants oscillators for FM.

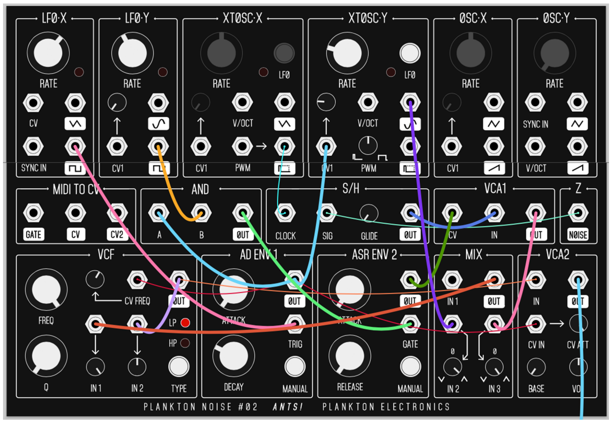


Figure 5.2: Plankton Ants Drum Machine Patch. Kick and snare played by the LFOs. Filter feedback for distortion. LFOY synced to LFOX through the AND gate (thinner patch cables are normalised connections). [46]

5.2.3 Unstructured use and Improvisation

When these tasks had been completed, unstructured use of the module was encouraged, first with the internal sound and modes of the Motorique, and then for patching with the Ants, as outlined above.

5.3 Data Collection and Evaluation Methods used for Current Project

5.3.1 System Usability Scale - List of Statements and Usage

System Usability Scale - List of Statements [37]

1. I think that I would like to use this product frequently.
2. I found the product unnecessarily complex.
3. I thought the product was easy to use.
4. I think that I would need the support of a technical person to be able to use this product.
5. I found the various functions in the product were well integrated.
6. I thought there was too much inconsistency in this product.
7. I imagine that most people would learn to use this product very quickly.
8. I found the product very awkward to use.
9. I felt very confident using the product.
10. I needed to learn a lot of things before I could get going with this product.
11. Overall, I would rate the user-friendliness of this product as:

5.3.2 Additional Function and Mode Specific Questions

These questions were asked to gather more detailed quantitative data about specific features and improvisation with the module, whereas usability testing gathers data about the device as a whole. Data was collected on a five-point likert scale (1 - strongly disagree, 5 - strongly agree). However, in contrast to the alternate positive/negative nature of the statements in usability testing, all statements were positive.

Additional Likert Scale - List of Statements

1. Interaction with the rotating wheel for setting and altering frequency of the oscillator (internal) was engaging.
2. Interaction with the rotating wheel for setting and altering frequency of the oscillator (external) was engaging.
3. I can think of a variety of uses for this module.

4. The different modes were easy to navigate between.
5. The functions of the motor, potentiometers and buttons made sense.
6. The layout and labelling of the motor, potentiometers and buttons on the panel made sense.
7. Once the system was explained to me, I found it rewarding to improvise with the device (internal).
8. I found it rewarding to improvise with the device as an interface for interacting with other modules (Tempo and Frequency).
9. Issues with the internal audio did not interfere with me using the system, or there were none.
10. Issues while interfacing with other modules did not interfere with me using the system, or there were none.

5.3.3 Video-cued Recall

The author could only find a small number of cases where video-cued recall has been used for evaluation of DMIs (or related audio-visual artistic projects). In terms of performers, examples of its usage for these purposes can be seen in: [47] (two separate cases, the Very Nervous System and Tmema - The Manual Input Workstation), [36] and [48]. The author could not find any cases of this being used in the raw data from [29]. While video data has used in any many music technology related evaluations, it has been largely used for audience evaluations [35], and evaluations of collaborative music making [49].

The participants were observed during their completion of the set tasks and interaction with the system, and when four of the most prominent, unique or interesting interaction had occurred, time stamps were be noted from the video camera's LCD screen (also any time offset from the recorded audio). This was be done in order for clips to be selected quickly for playback to the user. After the tasks for usability testing were completed, the participant was given time for unstructured use of the interface and encouraged to improvise in order to maximize the potential for the user to interact with the interface in new and interesting ways. For example, if the user seemed to be intrigued by a particular feature of the system or used it in a unexpected way.

After viewing each video clip, the participant was asked to comment (in free-text) on the particular interactions with the system and emotions experienced during each of the video clips or use of that mode more generally. An example was given: I really enjoyed creating this sound/I felt confused at this point, etc.

Using Physiological measurements was considered as discussed in Chapter 2, as a way to select which clips should be played back to participants. One consideration was using the peaks from GSR data in order to select the clips for playback [33].

However due to the intrusiveness of most of the related apparatus for gathering this data, this approach was rejected. Regarding DMI evaluations for performers, this is certainly an area for future research, but until less invasive apparatus is developed, the question will remain as to whether the intrusive nature of the apparatus will affect the responses given by the participants. Finally, the participants were asked to write down any additional comments or suggestions for future iterations in free-text.

Chapter 6

Results and Discussion

6.1 Demographics and Sample Sizes

Eight participants were tested using between group testing for two different iterations of the module. Five participants tested the first iteration and three tested the second iteration. While this gave unbalanced sample sizes, it was necessary due to time constraints. Only a few hours were available for making changes before testing the second iteration, and the changes (detailed in Chapter 5) largely related to known issues with the first iteration and information gathered from qualitative data given by participants who completed testing of the first iteration (detailed in Qualitative Data Analysis, towards the end of this chapter).

All participants were males between the ages of 24 and 34, studying Sound and Music Computing at Aalborg University in Copenhagen. This could be considered as a bias. Half of the participants could be considered as experts 6.1, with more than ten years of general musical experience (including performing, composing or studying related subjects).

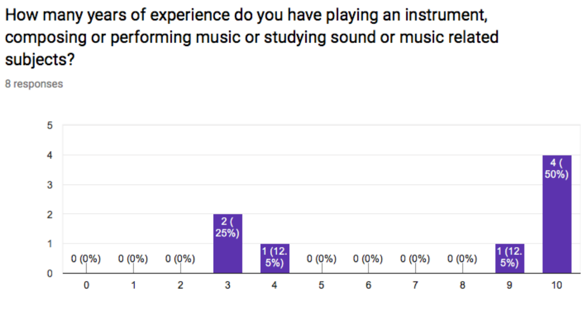


Figure 6.1: Level of Expertise.

Most participants were active users of modular synthesizer style software - 62.5%, with just 12.5% having little to no experience and 25% occasionally using them 6.2.

However, most participants had little to no experience of using hardware modular

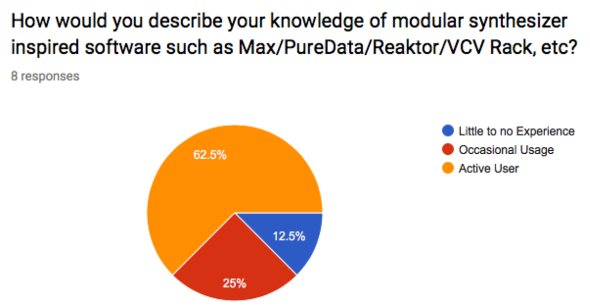


Figure 6.2: Usage of Modular Synthesizer Style Software.

synthesizers - 50%, with just 12.5% being active users and 37.5% occasionally using them 6.3.

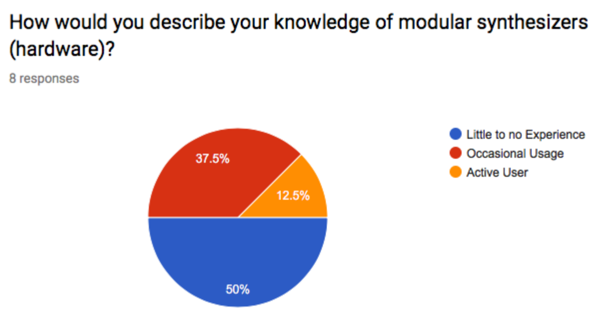


Figure 6.3: Usage of Hardware Modular Synthesizers.

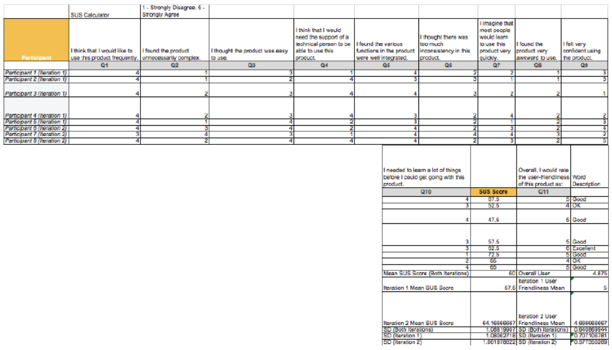
6.2 Study Limitations

The small sample size meant that generalisations cannot be made as to the wider population based on the gathered data, or indeed to experts of modular synthesizers as a low percentage were active users of modular hardware. Given more time, the author would have travelled to Brno in the Czech Republic to test the module with more active users of modular synthesizers at Bastl Instruments, including engineers, designers, performers and recording artists, who use these tools on a far more regular basis as they all work for an established modular synthesizer company. Most of which could be considered experts within the niche field of modular synthesizers.

6.3 Quantitative Data Analysis

6.3.1 SUS Scores

As detailed in Chapter 3, the SUS scores for each participant and the mean SUS score for all participants was calculated. Details of this can be seen in Fig. 6.4.



	SUS Calculator	1 - Strongly Disagree, 5 - Strongly Agree											
Participant	I think that I would like to use this product frequently.	I found the product unnecessarily complex.	I thought the product was easy to use.	I think that I would need the support of a technical person to be able to use this product.	I found the various functions in the product were well integrated.	I thought there was too much inconsistency in this product.	I imagine that most people would learn to use this product very quickly.	I found the product very awkward to use.	I felt very confident using the product.	I needed to learn a lot of things before I could get going with this product.		Overall, I would rate the user-friendliness of this product as:	Word Description
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	SUS Score	Q11	
Participant 1 (Iteration 1)	4	1	3	1	4	2	2	1	3	4	67.5	5	Good
Participant 2 (Iteration 1)	4	1	2	4	3	3	1	1	3	3	52.5	4	OK
Participant 3 (Iteration 1)	4	2	3	4	4	3	2	2	1	4	47.5	5	Good
Participant 4 (Iteration 1)	4	2	3	4	3	2	4	2	2	3	57.5	5	Good
Participant 5 (Iteration 1)	4	1	4	2	3	2	1	2	3	3	62.5	6	Excellent
Participant 6 (Iteration 2)	4	3	4	2	4	2	3	2	4	1	72.5	5	Good
Participant 7 (Iteration 2)	3	4	3	1	4	4	4	3	2	2	55	4	OK
Participant 8 (Iteration 2)	4	2	4	4	4	2	3	2	5	4	65	5	Good
										Mean SUS Score (Both Iterations)	60	Overall User	4.875
										Iteration 1 Mean SUS Score	57.5	Iteration 1 User Friendliness Mean	5
										Iteration 2 Mean SUS Score	64.16666667	Iteration 2 User Friendliness Mean	4.666666667
										SD (Both Iterations)	1.08819907	SD (Both Iterations)	0.640869944
										SD (Iteration 1)	1.08062718	SD (Iteration 1)	0.707106781
										SD (Iteration 2)	1.061878822	SD (Iteration 2)	0.577350269

Figure 6.4: SUS Scores.

A line chart for comparisons between the adjective SUS ratings [37], overall mean, and mean for each of the two iterations can be seen in Fig. 6.5. All of the above fall into the category of OK and are lower than the average SUS score of 68 (acceptability rating in Fig. 3.1). The mean of iteration 2 has a marked improvement upon the mean of iteration 1, but due to the small sample sizes involved, must be viewed with caution and cannot be generalised. The medians of each iteration are as follows: iteration 1 = 3.55, iteration 2 = 4.

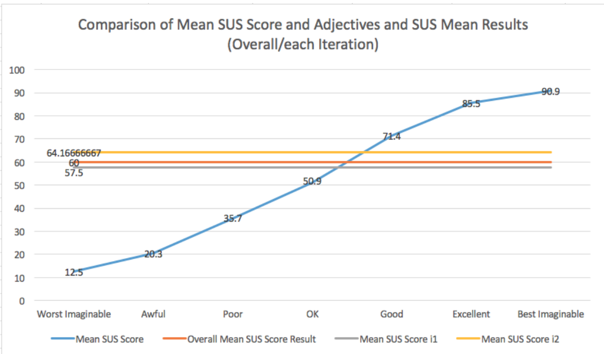


Figure 6.5: Comparison of Mean SUS Score Adjective Categories and SUS Mean Results (Overall/each Iteration).

6.3.2 Feature, Improvisation and Interaction Related Questions and Discussion

Relation of Questions to Design Requirements and Possible Causes between Iterations

The design requirements set out in Chapter 4 link directly to a number of these questions. Each of which are discussed below and details relating to possible causes due to changes between iterations, discussed. However, the possible bias in the resulting means and standard deviations due to the small, unbalanced sample size must be considered.

	Interaction with the rotating wheel for setting and altering frequency of the oscillator (internal) was engaging.		Interaction with the rotating motor wheel for setting and altering tempo (external) was engaging.		Interaction with the rotating wheel for setting and altering frequency of the oscillator (external) was engaging.	
	Q12		Q13		Q14	
	i1	i2	i1	i2	i1	i2
	3	4	5	4	5	4
	4	2	5	2	3	4
	4	4	2	4	3	5
	2		4		2	
	4		4		2	
Mean	3.4	3.33333333	4	3.33333333	3	4.33333333
SD	0.894427191	1.15470054	1.224744871	1.15470054	1.224744871	0.57735027

Figure 6.6: Motor Wheel Interaction Questions.

The questions in Figure 6.6 link to the design requirement that the RPM of the motor should be perceptually linked to the resulting frequency or clock speed and this interaction should be engaging. The question about interfacing with other modules also relate to the requirement that the module should be capable of sending control voltage (CV) signals to other modular devices for control or modulation of tempo or frequency. The means for engagement of the interaction between RPM and frequency for the internal modes of the module were very similarly rated for each iteration. There was more of a difference between this interaction for interfacing with external modules (Q13 and 14) for each iteration (tempo and frequency). Tempo interaction was rated as better for the first iteration, which may point to participants preferring a larger range of control for tempo modulation, as a more limited range was used for this purpose in the second iteration, thus less dramatic changes were possible. Frequency, however was rated as better for the second iteration, possibly due to FM being used rather than a non-optimally functioning V/Oct mode used in the first iteration. The higher motor wheel and its intention to improve accuracy of the hardware interrupts was also a possible cause for this.

	I can think of a variety of uses for this module.	
	Q15	
	i1	i2
	5	2
	4	4
	4	5
	4	
	5	
Mean	4.4	3.66666667
SD	0.54772256	1.52752523

Figure 6.7: Variety of Uses Questions.

The question in Figure 6.7 link to the design requirement that the module should provide a variety of different modes for use with the internal sound engine and interfacing/controlling other modules. The mean was approximately 0.7 higher for the first iteration. In general, this may have been due to participants generally spending more time with the device during the first iteration. The removal of potentiometer control of delay time for the second iteration could also have influenced this.

	Once the system was explained to me, I found it rewarding to improvise with the device. (internal audio)		I found it rewarding to improvise with the device as an interface for interacting with other modules (Tempo and Frequency).	
	Q19		Q20	
	i1	i2	i1	i2
	4	5	5	5
	5	4	3	4
	4	5	4	5
	3		5	
	4		5	
Mean	4	4.66666667	4.4	4.66666667
SD	0.707106781	0.57735027	0.894427191	0.57735027

Figure 6.8: Improvisation Questions.

The questions in Figure 6.8 relate to the ability of the module to allow the user to create a sound or timbre they find engaging or pleasing through improvisation. The means for these questions were both higher for the second iteration, possibly due to one mode (V/Oct) functioning in a non-optimal manner. Another possible cause could have been the tempo mapped LFO or the use of the LFOs for FM synthesis of external oscillators. Issues with the internal audio relating to potentiometer control of delay speed may have also influenced the higher mean for the internal modes.

	Issues with the internal audio did not interfere with me using the system, or there were none.		Issues while interfacing with other modules did not interfere with me using the system, or there were none.	
	Q21		Q22	
	i1	i2	i1	i2
	3	4	4	4
	3	5	2	5
	2	5	4	5
	2		1	
	2		2	
Mean	2.4	4.66666667	2.6	4.66666667
SD	0.547722558	0.57735027	1.341640786	0.57735027

Figure 6.9: Issues with Module Questions.

The questions in Figure 6.9 relate to the design requirement that each of the oscillators should be switchable in terms of mode (LFO, VCO or FM), such that they could be used individually as an audio (internal/standalone) or CV output (for controlling other modules). These questions also relate to the requirement that the module should be capable of sending control voltage (CV) signals to other modular devices for control or modulation of tempo or frequency. The differences between each iteration for the above questions were more significant than all of the other comparisons made previously. One would presume this, for the internal audio, to be related to the removal of glitches in the second iteration due to potentiometer control of delay time, which significantly improved the audio quality, while reducing the amount of features for improvisation 6.8. Also the higher motor wheel, implemented in order to improve the accuracy of triggering hardware interrupts may have influenced the higher mean for the second iteration (internal and external), in addition to the V/Oct mode not functioning correctly.

6.3.3 Further Statistical Analysis

Due to the small, unbalanced sample sizes, many statistical tests such as ANOVA, if carried out on the more specific questions (5 point likert scale), would produce type I error. Type I error causes a false positive rejection of the null hypothesis, when in fact it is the correct result. Other issues with the sample sizes include the caveat that due to the very small sample sizes for both iterations used for testing (three and five participants), the below test for homogeneity of variance (Levene's test) may be lacking in sufficient statistical power [50] to provide accurate results.

Another consideration would be the switching from the alternating positive/negative statement nature of the SUS and the all positive statement likert scale used for these questions. This was explained to all participants, but one cannot account for human error and the fact that it was switched half way through possibly made answering the statements more confusing. However, as all participants were Sound and Music Computing students, they all will have most likely created their own DMIs and possibly experimental designs for evaluating them, which could have included SUS as this is a popular method in this field.

Levene's Test

Levene's test was used in order to assess whether the two samples had equal variance (homogeneity of variance). This was done by performing ANOVA on the absolute difference between the mean and the scores for each value in each iteration. Levene's test is also suitable for non-normally distributed data, such as likert scales.

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
i1 Difference	55	50.1454545	0.911735537	0.401156023
i2 Difference	33	22.8484848	0.692378329	0.427979868

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.992425189	1	0.992425189	2.413855276	0.123938366	3.951882408
Within Groups	35.35778101	86	0.411136988			
Total	36.35020619	87				

Figure 6.10: Results of Levene's test.

The results of Levene's test can be seen in Fig. 6.10. The p-value (0.123938366) is more than 0.05 so we must accept the null hypothesis that the two samples are homogeneous in terms of variance. The data was therefore not found to be heteroscedastic. However, the results could be viewed with some skepticism, again due to the small sample sizes. Consequently, it was decided that no further statistical tests would be carried out and the raw data presented in C.

Given more time, a Tukey-Kramer test would have been carried out on the data, due to its unbalanced, small sample size and homogeneity of variances. A non-parametric, conservative option was also considered due to the and non-normal distributional nature of likert scales. However, completing a test of this nature on an unbalanced and small sample would reduce the statistical power of its results even further.

6.4 Qualitative Data Analysis

Content analysis was done on the qualitative data collected from free-text answers relating to specific interactions with the module based on video-cued recall. This was done in order to easily ascertain which mode or part of the DMI, the user was referring to in each answer. This can be seen in B. This was done by colour for ease of visualisation (shown in the key at the top), but a quantitative count for each is also provided.

As free-text boxes were used for data collection, it was harder for participants to go in-depth compared to interviews. Free text responses have limited richness in terms of qualitative data. Many of the participants mentioned issues during use (similar in nature to think-aloud tests) even though they were not asked to do this. However, they were prompted about prior comments if it related to the clip which they had just viewed and were not sure of what to write, while attempting not to bias their responses.

With more time and possibly a research assistant recruited, full interviews and transcribing would be used for increased depth and richness of the qualitative data gathered.

However some interesting insights were still gained from analysis of the responses. In fact actually creating a hierarchy of important changes to be implemented before testing the second iteration. Some interesting insights included the opinion that while user-friendliness and usability was being asked about when using SUS; modular synthesizers are likely to seem inherently non-user friendly or intuitive to the uninitiated due to the steep learning curve involved.

One participant (iteration 1) noted that “I didn’t understand what happens when the wheel completely stops, and the responsiveness also felt like it was interfering with my experience", the responsiveness was improved slightly by the higher motor wheel implemented in iteration 2, but some participants mentioned issues with latency in this iteration also. Lots of the participants mentioned the glitches in the internal audio in iteration 1 as being an issue.

Generally, the FM mode was more well received than the VCO mode. This was expected due to more possibilities in terms of timbre, while using the VCO mode first also may have helped the users to understand the system better. Control of the modulating frequency being mapped from RPM rather than the carrier may have influenced this also.

Some participants mentioned possibility for use in live performance and improvisation. Specifically with the FM (internal) mode, “I could imagine experimenting with these sounds in a live performance. The sonic palette felt more expansive and I felt wider control that allowed me to experiment."

There were differences in opinion as to whether the rotating, visual representation of tempo and frequency were preferred. One participant mentioned during testing of the first iteration, that while they found the interaction and representation interesting, they thought that the “RPM-BPM relation would work much better being exponential (sic: rather) than linear (BPM went too fast too quick)". Due to the short amount of time available for changes between iterations, an additional tempo mapped LFO was instead implemented for control of tempo. Another participant suggested that a CV input would increase the variety of uses for the module.

Another participant who was new to modular synthesis mentioned that they “thought it was an interesting experience to relate the physical turning of the motor to the drum sound. As a novice who has little experience with modular devices, it’s nice to have something I can understand (a physical turning of the wheel) to represent what’s going on."

6.5 Future Works and Planned Optimisation

The first step would be to finalise the choice of components (possibly changing the optical sensor and motors for faster response and speed), and then create a PCB. This iteration would then be tested again with a balanced (if two iterations compared) and far larger sample size to get a wider variety of feedback and responses, also with modular experts at Bastl Instruments. If no significant issues were found, a DIY kit (or at least a PCB) would be made available for purchase. Luckily as the author has connections at Bastl Instruments, guidance could be obtained easily in terms of this and the future of the project as a whole. Below is a list of issues with the system that would need to be solved before this could take place:

1. Ensure hardware interrupt accuracy in terms of components and software.
2. Exponential mapping of frequency and tempo.
3. Minimise latency.
4. Stable frequency and BPM output when RPM remains static.
5. When motor wheel is stalled, no output, rather than an arbitrary frequency.
6. Fix power/grounding issues (Teensy turning off).
7. Implementation of variable speed delay time without audible artefacts.

8. Fix V/Oct mode for correct output in order to control frequency of external oscillator rather than just modulating them.

Other possible improvements include CV inputs for control of the internal modes by other modules, possibly larger hp (width of module) for increased motor wheel diameter. Another idea would be to implement a quadrature encoder motor wheel in order to differentiate between forward and reverse rotation direction of the motor. This could then be mapped to some sort of change in the resulting output.

Chapter 7

Conclusion

Control of tempo and frequency through modulation of motor speed has been investigated through using an iterative design process, various stages of implementation and evaluation of the created Eurorack module.

Two iterations were tested with five participants for the first iteration and three for the final iteration. An initial paper prototype was also evaluated by a Bastl Instruments employee (and modular synthesizer expert). Thus, initial feedback was received about the module's design from a professional within the industry. Between iterations, as many improvements as possible were implemented in the short timespan, largely relating to known issues or comments from participants noted during testing of the first iteration. However, many improvements would be necessary in order for this to be a viable commercial product.

Different methods and frameworks for evaluation of DMIs were reviewed and a suitable combination of methods chosen. However, due to time constraints and technical issues, convenience sampling was necessary to obtain participants. This resulted in a small and unbalanced sample size being obtained, which made it hard to generalise from the results and limited the use of possible statistical tests available. Usability Testing and video-cued recall were used to obtain both quantitative and qualitative data (mixed method) during evaluation.

The relationship between tempo, frequency and motor speed was explored, in musical terms. This was done in order to assess the potential for musical interaction. The need for further experimentation with tempo modulation as a form of musical expression in electronic music (and more specifically dance music) was also discussed.

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Appendix A

Informed Consent Form

Consent Form - Motorique Testing

1. We will ask you to perform a number of tasks with the purpose of observing how you interact with the module.
2. Once these have been completed, you will be asked to complete a questionnaire about your experience with the system.
3. After you have completed the questionnaire, you will be presented with four video clips from the completed tasks and asked to comment on the interactions with the system and emotions experienced during each clip. (Video Cued Recall)

By signing this contract, you agree to the following terms:

- This study is anonymous. We will not be collecting or retaining any information about your identity.
- I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason.
- We wish to record the interview using video and audio. This is solely for educational purposes. We may use some of the footage for a presentation video of the project. Please specify how we can use the footage in the box below:

__ I don't want any of the interview to be recorded. (No Video Cued Recall)
__ You can use all of the recorded footage for educational purposes
__ You can use some parts of the interview for educational purposes. Please specify below:

____

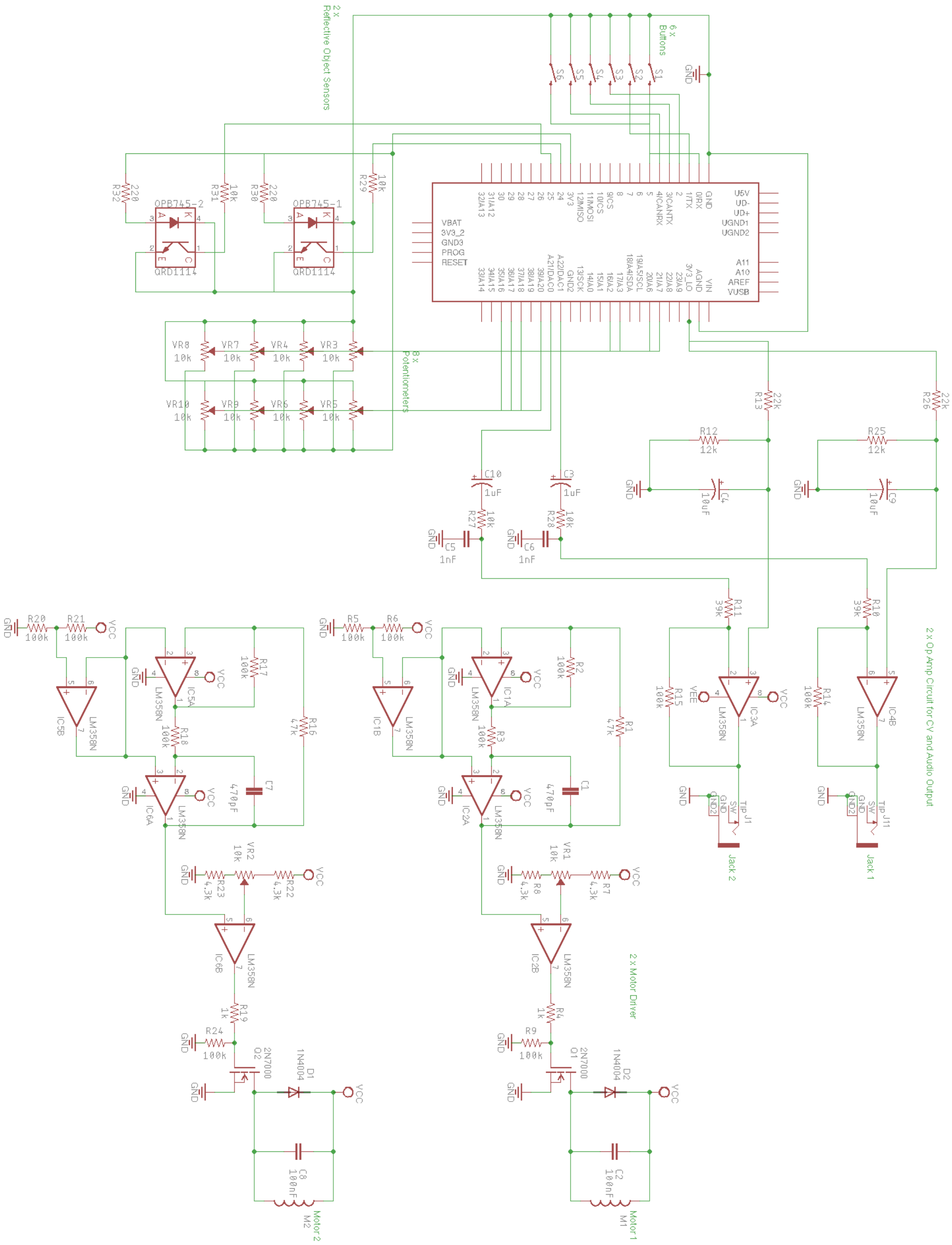
Name: ______________________________

Signature: ______________________________

Date: ______________________________

Appendix B

Final Eagle Schematic



Appendix C

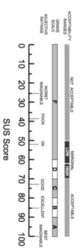
Quantitative Raw Data

Participant	Timestamp	Age	How many years of experience do you have playing an instrument, composing or performing music or studying sound or music related subjects?	How would you describe your knowledge of modular synthesizer inspired software such as Max/PureData/Reaktor/VCV Rack, etc?	How would you describe your knowledge of modular synthesizers (hardware)?
Participant 1 (Iteration 1)	9/5/2018 19:03:06	29	3	Occasional Usage	Little to no Experience
Participant 2 (Iteration 1)	9/5/2018 21:18:07	29	3	Active User	Little to no Experience
Participant 3 (Iteration 1)	9/6/2018 14:29:15	27	4	Active User	Little to no Experience
Participant 4 (Iteration 1)	9/6/2018 16:04:05	33	10	Active User	Little to no Experience
Participant 5 (Iteration 1)	9/6/2018 17:32:10	26	10	Active User	Active User
Participant 6 (Iteration 2)	9/7/2018 13:11:09	29	10	Little to no Experience	Occasional Usage
Participant 7 (Iteration 2)	9/7/2018 15:08:12	24	9	Occasional Usage	Occasional Usage
Participant 8 (Iteration 2)	9/7/2018 16:34:35	34	10	Active User	Occasional Usage

SUS Calculator — 1 - Strongly Disagree, 5 - Strongly Agree

Participant	I think that I would like to use this product frequently.	I found the product unnecessarily complex.	I thought the product was easy to use.	I think that I would need the support of a technical person to be able to use this product.	I found the various functions in the product were well integrated.	I thought there was too much inconsistency in this product.	I imagine that most people would learn to use this product very quickly.	I found the product very awkward to use.	I felt very confident using the product.	I needed to learn a lot of things before I could get going with this product.		Overall, I would rate the user-friendliness of this product as:	Word Description
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	SUS Score	Q11	
Participant 1 (Iteration 1)	4	1	3	1	4	2	2	1	3	4	67.5	5	Good
Participant 2 (Iteration 1)	4	1	2	4	3	3	1	1	3	3	52.5	4	OK
Participant 3 (Iteration 1)	4	2	3	4	4	3	2	2	1	4	47.5	5	Good
Participant 4 (Iteration 1)	4	2	3	4	3	2	4	2	2	3	57.5	5	Good
Participant 5 (Iteration 1)	4	1	4	2	3	2	1	2	3	3	62.5	6	Excellent
Participant 6 (Iteration 2)	4	3	4	2	4	2	3	2	4	1	72.5	5	Good
Participant 7 (Iteration 2)	3	4	3	1	4	4	4	3	2	2	55	4	OK
Participant 8 (Iteration 2)	4	2	4	4	4	2	3	2	5	4	65	5	Good

Mean SUS Score (Both Iterations)	60	Overall User	4.875
Iteration 1 Mean SUS Score	57.5	Iteration 1 User Friendliness Mean	5
Iteration 2 Mean SUS Score	64.16666667	Iteration 2 User Friendliness Mean	4.66666667
SD (Both Iterations)	1.08819907	SD (Both Iterations)	0.64086994
SD (Iteration 1)	1.08062718	SD (Iteration 1)	0.70710678
SD (Iteration 2)	1.061878622	SD (Iteration 2)	0.57735027



Likert Scale (Positive Statement) Results — 1 - Strongly Disagree, 5 - Strongly Agree

	Interaction with the rotating wheel for setting and altering frequency of the oscillator (internal) was engaging.	Interaction with the rotating motor wheel for setting and altering tempo (external) was engaging.	Interaction with the rotating wheel for setting and altering frequency of the oscillator (external) was engaging.	I can think of a variety of uses for this module.	The different modes were easy to navigate between.	The functions of the motor, potentiometers and buttons made sense.	The layout and labelling of the motor, potentiometers and buttons on the panel made sense.	Once the system was explained to me, I found it rewarding to improvise with the device. (internal audio)	I found it rewarding to improvise with the device as an interface for interacting with other modules (Tempo and Frequency).	Issues with the internal audio did not interfere with me using the system, or there were none.	Issues while interfacing with other modules did not interfere with me using the system, or there were none.		Individual Participant Means
	Q12	Q13	Q14	Q15	Q16	Q17	Q18	Q19	Q20	Q21	Q22		
Participant 1 (Iteration 1)	3	5	5	5	5	5	5	4	5	3	4		4.45454545
Participant 2 (Iteration 1)	4	5	3	4	5	5	5	5	3	3	2		4
Participant 3 (Iteration 1)	4	2	3	4	4	4	4	4	4	2	4		3.54545455
Participant 4 (Iteration 1)	2	4	2	4	3	4	5	3	5	2	1		3.18181818
Participant 5 (Iteration 1)	4	4	4	5	2	4	5	4	5	2	2		3.72727273
Participant 6 (Iteration 2)	4	4	4	2	3	5	4	5	5	4	4		4
Participant 7 (Iteration 2)	2	2	2	4	4	5	4	4	4	5	5		3.72727273
Participant 8 (Iteration 2)	4	4	5	5	5	4	4	5	5	5	5		4.63636364
Per Question Mean	3.375	3.75	3.5	4.125	3.875	4.5	4.5	4.25	4.5	3.25	3.375	Mean (Both Iterations)	3.90909091
Per Question Mean i1	3.4	4	3.4	4.4	3.8	4.4	4.8	4	4.4	2.4	2.6	Iteration 1 Mean	3.78181818
Per Question Mean i2	3.333333333	3.333333333	3.666666667	3.666666667	4	4.666666667	4	4.666666667	4.666666667	4.666666667	4.666666667	Iteration 2 Mean	4.12121212
SD (Both Iterations) PQ	0.916125381	1.164964745	1.195228609	0.991031209	1.125991626	0.534522484	0.534522484	0.707106781	0.755928946	1.281739889	1.505940617		
SD (Iteration 1) PQ	0.894427191	1.224744871	1.140175425	0.547722558	1.303840481	0.547722558	0.447213595	0.707106781	0.894427191	0.547722558	1.341640786		
SD (Iteration 2) PQ	1.154700538	1.154700538	1.527525232	1.527525232	1	0.577350269	0	0.577350269	0.577350269	0.577350269	0.577350269		

PQ = Per Question

Appendix D

Qualitative Raw Data

Key:	Mode Totals
LFO INT	N/A
VCO INT	ALL USERS
FM INT	ALL USERS - 1 user * 2
LFO EXT TEMPO	7 - 1 user * 2
LFO EXT FREQ	3
LFO EXT MAPPED	2
V/OCT	3
Participant	Clip 1
Participant 1 (Iteration 1)	I didn't understand what happens when the wheel completely stops, and the responsiveness also felt like it was interfering with my experience
Participant 2 (Iteration 1)	Enjoyed playing with the delay time and feedback. At first difficult, but could achieve interesting after a while.
Participant 3 (Iteration 1)	I enjoyed this part, I found easy and fast to create interesting and pleasant sounds.
Participant 4 (Iteration 1)	The sounds that I experimented with were very nice, I liked the sonic aesthetic quality. It was a bit of a challenge getting into the experience to be fully engaging.
Participant 5 (Iteration 1)	I made some crazy sounds, it was fun.
Participant 6 (Iteration 2)	At that moment I was trying to figure out what the device was doing, and trying to figure out how the spinning wheels were working. It was fun to explore the sound possibilities of the VCO, etc
Participant 7 (Iteration 2)	It was cool just trying out the device. The feedback delay definitely made it more fun to use the device. I was a bit confused by the latency and the general audio mayhem.
Participant 8 (Iteration 2)	it was a pleasant experience , creating improvised sounds of the late fifties with an experimental, generative nature, somehow like the BBC radiophonic workshop
	Clip 2
Participant 1 (Iteration 1)	I particularly enjoyed the FM synthesis part, as it offered a lot of dimensions of control to explore
Participant 2 (Iteration 1)	much more creativity possible! again the delay was awesome. sometimes confusing at the start, but understood quite well the system at the end.
Participant 3 (Iteration 1)	I enjoyed this part as well, there was many possibilities without increasing difficulty considerably.
Participant 4 (Iteration 1)	I liked this mode much more than the first. I could imagine experimenting with these sounds in a live performance. The sonic palette felt more expansive and I felt wider control that allowed me to experiment with.
Participant 5 (Iteration 1)	The VCO sounded good, some glitches, maybe a CV input would make it even better
Participant 6 (Iteration 2)	I was exploring the possibilities of the LFO and the delay feedback. I enjoyed making those sounds, and finally I was controlling more the sounds that I wanted to create.
Participant 7 (Iteration 2)	I was pleasantly surprised by the FM mode compared to the previous mode. More possiblities with regards to timbre. However I didn't really understand what the different buttons right away, so at first it was just random knob tweaking.
Participant 8 (Iteration 2)	playing with FM with excellent range in carrier, modulator and rate. the feeling was exciting with FM since it has the nature of harsher brassy tonality .
	Clip 3
Participant 1 (Iteration 1)	I felt that the physical indicator is more intuitive than a knob or slider position
Participant 2 (Iteration 1)	i would still prefer to set the frequency with a pot, but i think it is interesting but it may take some time to get used to and possibly a better implementation
Participant 3 (Iteration 1)	I found this way of controlling an external device interesting and intuitive. However, I think the RPM-BPM relation would work much better being exponential than linear (BPM "went too fast too quick").
Participant 4 (Iteration 1)	I thought it was an interesting experience to relate the physical turning of the motor to the drum sound. As a novice who has little experience with modular devices, it's nice to have something I can understand (a physical turning of the wheel) to represent what's going on. I felt though that the speed of the wheel could have been mapped better to the output so it would feel more intuitive (aka. the speed of the wheel would represent what I feel the speed of the tempo is) Setting the tempo of the external device was fairly engaging, allowing me to experiment with the different modes of the device. I enjoyed the extreme parameter settings, slowly spinning RPM, then ramping it up to the fastest speed.
Participant 5 (Iteration 1)	Made some weird stuff, it was great!
Participant 6 (Iteration 2)	I was starting to experiment with the tempo of the beat, etc. It was just the beginning of this part, so still I didn't know all the possibilities of the module, but it felt easy to change the beat parameters.
Participant 7 (Iteration 2)	The interaction was quite fun, however it was weird that the range of the wheel RPM did not correspond to the musical tempo. The latency is still a problem.
Participant 8 (Iteration 2)	the relationship between the physical movement of the wheels with tempo of the sync signal was spot on!
	Clip 4
Participant 1 (Iteration 1)	Frequency and the speed of rotation is easily relatable to each other, and just like the question above, as an indicator it felt intuitive as well
Participant 2 (Iteration 1)	I am not familiar with modular synth and too many connections. so my focus was put more on the ants, which was for me dominating the interaction. however i found some patch connections that were affected more by the motorique.
Participant 3 (Iteration 1)	I found this part a bit confusing, could not really understand how the model was controlling the external device
Participant 4 (Iteration 1)	It would have been nice if I was able to set the frequency as expected, unfortunately this was not the case.
Participant 5 (Iteration 1)	The potentiometer worked in weird way controlling the LFO frequency. But when it worked it was fun
Participant 6 (Iteration 2)	At this point I already knew how to control the different parameters and knew how to shape a decent techno beat. It was fun, and the interfaces (wheels device plus rack) where intuitive to work with.
Participant 7 (Iteration 2)	Pretty much the same as clip 3. It would be cool to use both LFOs at the same time to control both the beat and the frequency.
Participant 8 (Iteration 2)	the use of of two sync signals with their assigned wheels ,I could create a complex interesting polyrhythmic patterns with clear visualisation .
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	Any additional comments?
Participant 1 (Iteration 1)	the size and the material of the wheels made it hard to interact with them(manually slowing them down or speeding them up) i was hoping to be able to get a steady rpm value out
Participant 2 (Iteration 1)	I liked having a visual representation of the frequency to interact with, especially for tempo.
Participant 3 (Iteration 1)	In general I think the module brings a new and interesting, as well as novel for me (never seen it before for a synthesiser), way of interacting for both the module itself and external devices. Only considerable setback was the number of artefacts I listened to when moving knobs, also the fact of still hearing something when the RPM was set to 0 was a bit confusing. In general.. VIBEZ
Participant 4 (Iteration 1)	N/A
Participant 5 (Iteration 1)	Really cool stuff, just a few glitches here and there. If they are solved this would be an awesome product. I would like even more sensitivity on the wheel sensors, so you can really create random modulations with the lfo's. I liked the buzz noises from the motors, cool gimmick!
Participant 6 (Iteration 2)	There was some interference between both wheels that added a randomness in the tempo that was quite interesting, although I think it was not intentional.
Participant 7 (Iteration 2)	I really want to interact with the wheel and be able to turn it by hand. The latency made everything feel unresponsive. Maybe have a super simple mapping of the motor speed to make the connection more obvious.
Participant 8 (Iteration 2)	I'm looking forward to using this product with better components in the final casing, which can then be used in live performances :)