Designing expressive engagement with electronic and hyper instruments

The Electrumpet a case study

by Hans Leeuw

Submitted in partial fulfillment of the
requirements for the degree of
PhD
in The School of Music, Humanities and Media
University of Huddersfield 2019

Abstract

Using values-led participatory design (Iversen, Halskov, & Leong, 2013) as a foundation, this thesis argues the importance of values in the design decisions that steer the conception and development of new electroacoustic musical instruments. A model is introduced that defines seven distinct Personas, as different perspectives on the creation process of 'performing instrument designers'. *Second Order Virtuosity* (Hildebrand, Lopes, Hoelzl, & Campo, 2016) and the persona model are cross-examined, substantiated by the virtuoso practice of peer 'performing instrument designers' (PIDs). The Electrumpet, a hyper instrument, is used as a case study for the application of the model in relation to its improved design and the evaluation of its progress as a musical instrument in general. The thesis concludes with a description of the technical implementation of the improved Electrumpet system and the compositional and improvisational strategies implemented.

Table of contents:

Front page (Artwork by Victor de Boo) 1

Abstract 3

Contents 4

Acknowledgements 8

Chapter 1 Introduction: 10
1.1 What is the Electrumpet 11
1.2 Thesis overview 13

Chapter 2 The Electrumpet before the PhD 14
2.1 The Electrumpet in the context of earlier artistic work 14
2.1.1 Early experiences using live electronics 14
2.1.2 Tetzepi and the Electrumpet 15
2.1.3 Other musical practice influencing the Electrumpet development 16
2.1.4 The musical practice of others that influenced the Electrumpet 16
2.1.5 Musical practice with the Electrumpet that influenced the Electrumpet 17
2.2 The conception of the Electrumpet 17
2.2.1 Hardware implementation 17
2.2.2 Software 18
2.2.3 Development overall 18
2.3 The Electrumpet in relation to the NIME discourse 19

Chapter 3 The persona model for musical instrument design 21
3.1 Introduction 21
3.2 The persona model for instrument design 22
3.2.1 Performer 23
3.2.2 Instrumentalist 23
3.2.3 Luthier 23
3.2.4 Musical improviser 24
3.2.5 Tinkerer 24
3.2.6 Composer 24
3.2.7 Designer 25
3.3 The axes of the persona diagram 25
3.3.1 Left / Right 25
3.3.2 Top / Down 26
3.4 Methodology, justification of the model 27
3.4.1 Iterative development of the persona model 31
3.5 Why should there be seven personas to capture the scope of musical instrument design? 33
3.6 Usefulness of the model in relation to (different) instrument designers 35

Chapter 4, the model in practice 36
4.1 Virtuosity and the model 36

4.2 Different definitions of virtuosity 36
4.3 Developing Second Order Virtuosity 38
4.3.1 Developing Second Order Virtuosity from an Instrumentalist perspective 38
4.3.2 Developing Second Order Virtuosity from a Performer perspective 39
4.3.3 Developing Second Order Virtuosity from a Luthier perspective 41
4.3.4 Developing Second Order Virtuosity from an Improviser perspective 42
4.3.5 Developing Second Order Virtuosity on the Electrumpet from a Tinkerer perspective 44
4.4 Virtuosity in relation to the composer and designer personas 45
4.4.1 Developing *Second Order Virtuosity* from a composer perspective 45
4.4.2 Developing *Second Order Virtuosity* from a designer perspective 46
4.5 The development of personal voice 47
4.6 Chapter conclusion 48

Chapter 5: Model versus Practice, the model applied to the Electrumpet 50
5.1 Electrumpet design from the instrumentalist persona perspective 51
5.1.1 Improvements in the Electrumpet design related to the instrumentalist persona 52
5.1.1.1 Ribbon controller and haptic feedback 54
5.1.1.2 Pressure sensors to digital valves 55
5.1.1.3 Infrared sensor to Gestic sensor 56
5.1.1.4 Adding a gate microphone 56
5.1.1.5 fixed microphone to clip microphone 57
5.1.1.6 9-axis sensor 58
5.1.2 Learnability 58
5.1.3 Reflection on the performer persona 59
5.2 Electrumpet design from the performer persona perspective 60
5.2.1 Development and Electrumpet specifics 62
5.2.2 No distraction on stage 62
5.2.2.1 Wireless connection and microphone freedom: 62
5.2.2.2 Streamlining 62
5.2.2.3 Embodiment, the phrase system and closed eyes 64
5.2.2.4 Repertoire 64
5.2.2.5 Being prepared and testing 65
5.2.3 Context and appearance 65
5.2.4 Reflection on the performer persona 66
5.3 Electrumpet design from the luthier persona perspective 66
5.3.1 The sound luthier 67
5.3.1.1 Harmoniser balance and quality 68
5.3.1.2 'post-processing' tools 68
5.3.1.3 Sound processing tools 69
5.3.1.4 Psychoacoustics and subjective perception 71
5.3.2 The electronic hardware luthier or electronic engineer 71
5.3.2.1 Sensors and actuators 72
5.3.2.2 Wireless connection 72
5.3.2.3 'Embedded' system 73
5.3.3 The artisan luthier or instrument maker 73
5.3.3.1 Brass frame 74
5.3.3.2 New digital valves 74

5.3.3.3 New casing for iphone and Gestic sensor 76
5.3.3.4 New casing for ribbon controller and haptic motors 77
5.3.3.5 Assembly of the new physical Electrumpet 78
5.3.3.6 Attachment frame for antenna, router and MacBook power adapter 79
5.3.4 Reflection on the luthier persona activities 80
5.4 Electrumpet design from the Improviser persona perspective 81
5.4.1 Improvisation on the Electrumpet, state of the art at the start of the PhD 82
5.4.2 Improvisation, evolution and new gained insights during the PhD 83
5.4.3 Improvisation, the current state of the instrument and reflection 85
5.5 Electrumpet design from the tinkerer persona perspective 87
5.5.1 The suitability for tinkering of the original Electrumpet system 88
5.5.2 Changes that influenced the suitability for tinkering in the new Electrumpet system 89
5.5.3 Tinkering, the current state of the instrument and reflection 89
5.6 Electrumpet design from the composer persona perspective 90
5.6.1 Composition at the start of the PhD 91
5.6.2 The evolution to "composing from the instrument" 91
5.6.3 'Composing from the instrument' and the new version 92
5.6.4 Reflection on the composer persona. 93
5.7 Electrumpet design from the designer persona perspective 93
5.7.1 Starting position of the designer persona in relation to the Electrumpet 94
5.7.2 Evolution of the designer persona 94
5.7.3 Persona model and redesign 95
5.7.4 Reflection on the designer persona 97
5.8 Reflection on the use of the persona model 97

Chapter 6, implementation of new insights in instrument design 100
6.1 What is the Essence of the new System? 100
6.2 Implementing virtuosity as core motif 100
6.3 The phrase idea: implementing virtuosity on the Electrumpet 101
6.4 The organisation of the phrases 101
6.4.1 Associative organisation 101
6.4.2 Interactive harmoniser model control 102
6.5 The audio modules 105
6.5.1 Switching and developing Sound modules 107
6.5.2 Make up of the Sound Modules 107
6.5.3 Make up of the input module and MUBU 107
6.5.4 Make up of the 'room and general sound attenuation' module 108
6.6 The eight current sound processing engines 108
6.7 Other relevant patch features 110
6.8 Chapter conclusion 110

Chapter 7 Composing from the instrument 111
7.1 Composing or designing 111
7.2 CfrI in relation to the instrumental action on the Electrumpet 112
7.2.1 Compositional considerations from the instrumental persona 112
7.2.2 Counterbalancing the instruments features 114
7.2.3 The use of live sampling before the system change 115
7.2.4 Organising time in the new system 115

7.3 CfrI in relation to the harmonic action on the Electrumpet 117
7.3.1 Interactive harmonizer 117
7.3.2 Chords per note defined from a counterpoint perspective 117
7.3.3 Abstract sets for which pitch recognition is less important 118
7.3.4 Sets of chords defined per note in the fixed chord order of a tune 118
7.3.5 Counterpoint voices in a fixed chord order of a tune 119
7.4 Arpeggiating chords 120
7.5 Microtonality 120
7.6 CfrI in relation to improvisation on the Electrumpet 121
7.7 Learning the instrument and developing virtuosity, etudes 121
7.7.1 'Knowing the instrument', a methodology 122
7.7.2 Etude, game pieces and the bucket system 123
7.8 Chapter conclusions 124

Chapter 8 Conclusions and future work 126
8.1 Future work 127
8.1.1 Instrumentalist 127
8.1.2 Performer 128
8.1.3.1 Hardware and artisan luthier 128
8.1.3.2 Sound luthier 128
8.1.4 Improviser 129
8.1.5 Tinkerer 129
8.1.6 Composer 129
8.1.7 Designer 130

References 131

APPENDIX A.1 Interview with Sam Pluta
APPENDIX A.2 Interview with Cléo Palacio Quentin
APPENDIX A.3 Interview with Frances Marie Uitti
APPENDIX A.4 Interview with Rajesh Mehta
APPENDIX A.5 Interview with Martin Marier
APPENDIX A.6 Interview with Tim Excile
APPENDIX A.7 Interview with Anne la Berge
APPENDIX A.8 Interview with Sarah Reid
APPENDIX A.9 Interview with Sebastian Schiesser
APPENDIX A.10 Interview with Arjen de Vreede
APPENDIX B Taxonomy of Interview coding
APPENDIX C Software explanation
APPENDIX D Software screenshots
APPENDIX E Bucket system screenshots
APPENDIX F Bucket system software
APPENDIX G List of works
APPENDIX H Inventory of sound interactions
APPENDIX I Sound belonging to the inventory list

Acknowledgements:

This PhD effort could not have taken place with a lot of people helping me. Some of them in a professional capacity, but a lot of people helped me without asking anything in return.

First of all I want to thank all the interview participants: Cleo Palacio Quentin, Sarah Reid, Anna la Berge, Frances Marie Uitti, Arjen de Vreede, Tim Excile, Sebastien Schiesser, Martin Marier, Rajesh Mehta and Sam Pluta. Sam also for playing together and the particular inspiration I got from his instrument.

A big word of thanks also to my supervisor Professor Pierre Alexandre Tremblay who has guided me to the PhD process with much more than what was expected of him. He was always there in moments of peril and has saved me from straying too long in the wrong direction and let me feel comfortable in the since long unfamiliar student role.

I also want to thank all my colleagues at the University of the Arts Utrecht for providing me with such an inspiring environment. Of course, this also goes out to my students and former students who show such enthusiasm in their own educational path. I want to especially thank my colleague Alex Geurink for lending me his professional ear for fine tuning the sound quality of the instrument and I also want to thank Maarten Kip for his help in the 3D milling of diverse components for the Electrumpet. All the other people assisting me in the workshops at the HKU a lot of thanks for the help as well. The people of the lectorate 'performatieve maakprocessen' I want to thank for their trust in me and their support in finishing this thesis.

My former colleagues at the Technical University Eindhoven have also been very helpful in the development of the Electrumpet. The instrument started out as an experimental student project in 2006. When I started designing myself though I have got a lot of useful tips from colleagues, especially Bert Lonsain, who gave me some pointers for the physical appearance of the instrument. Tilde Bekker pointed me in the direction of participatory design when I was searching for an angle to deal with my own bias and the bias of others towards musical instrument design.

I want to thank the colleagues, personnel and clientele of café the Engelbewaarder for putting up with the Electrumpet when it was still in its infancy. Victor de Boo deserves a lot of extra credit for not only being a fantastic drummer but also a good friend who spontaneously made the art work for the front cover of this thesis.

All the band members of Tetzepi and my former colleague band leader Esmée Olthuis I want to thank for going with my sometimes-crazy experiments in live-electronics.

Adrian Freed deserves a special word of thanks because he is responsible for accepting me into the NIME community and has been very important for the developments that took place in the early stages of the Electrumpet. The NIME community in total deserves a lot of credit as it is such an open community with

so much exchange of wonderful ideas from which I hugely benefitted and will benefit in the future.

All the programmers at IRCAM: much thanks for providing us artists with such wonderful software that is so very useful for artists like me. Of course, Diemo Schwarz deserves extra credit for those same efforts but also for teaching me ftm&Co and being a wonderful partner in our musical cooperation. I also want to thank Diemo for taking time to video tape our last joint session so it could be used in support of this thesis.

Unfortunately, in the process of this PhD I lost both of my parents. Luckily my father, an accomplished amateur musician, has had the opportunity to show his enthusiasm for the new Electrumpet developments before he passed away.

Chapter 1 Introduction:

Virtuoso performers have always been involved in the development of acoustic musical instruments, although their role in the invention of some major instruments, like the pianoforte, seems absent. But even today, the development of new features of classical musical instruments has been an initiative of musicians (Bijsterveld & Schulp, 2004, p. 663), with instrument makers focusing on improvement and experimentation within the tradition: *"Notwithstanding the instrument makers' inclination to experiment, many of their innovations originated after musicians had pointed out to them particular problems or needs."*. The instrument makers themselves drive innovation as well, although in general they have to deal with a conservative clientele.
Over the past few decades, the demarcation line between instrument maker and instrumentalist has begun to blur. This is probably due to technological developments, such as the accessibility of small low-cost electronics and electronic platforms like Arduino, the increased computing power of laptops and computers, and the availability of precise manufacturing tools for unskilled makers like 3D printing and CNC milling. Furthermore, the internet now provides a wealth of information for 'Do-It-Yourself'. Conferences like the New Instruments for Musical Expression (NIME) conference and the Linux Audio Conference (LAC) are platforms of exchange between designers, both professional and 'Do-It-Yourself'. There are diverse other local and international initiatives for the exchange of self-made electronic instruments.

Fabricating one's own instrument has become much easier and the skills involved can mostly be learned along the way. With the advance of all these new possibilities and their possible creative implementation, the concept of what constitutes a musical instrument has become less clear. Sarah-Indriyati Hardjowirogo developed the concept of instrumental identity (Hardjowirogo, 2016, pp. 17–21), defining a preliminary list of seven criteria needed for instrumentality:

- Sound Production
- Intention/Purpose
- Learnability/Virtuosity
- Playability/Control/Immediacy/ Agency/Interaction
- Expressivity/Effort/Corporeality
- "Immaterial Features"/Cultural Embeddedness
- Audience Perception/Liveness

This definition of instrumentality also defines the scope of this thesis regarding the definition of what constitutes a musical instrument.

With the introduction of computers in music, the relation between instruments that were made with computers and the sound produced by them became ambiguous. Aspects that were a given in all previous instruments were suddenly not. For an instrumentalist, one of the most noteworthy of these aspects is that there no longer has to be a direct relation between the instrumental action and the resulting sound. This relation has to be designed. (Ryan, 1991)

The new relation between instrument and instrumentalist means that the design of new instruments demands a very different skill set to the one needed by the traditional instrument maker. The new design and maker skills are not clearly defined and are continually in flux. For this PhD we were particularly interested in the professional performer operating in traditional performance contexts, for whom the physical interface played an important role in the practice. Do they have a skill set that could be translated to benefit the design of new musical instruments? Dobrian suggested (Dobrian & Kop, 2006, p. 281) that in order to reach 'the level of sophistication in musical expression achieved by major artists in other specialties (jazz, classical, etc)' it would be necessary to have 'dedicated participation by virtuosi (utilizing existing virtuosity and developing new virtuosity)', for example.

The Electrumpet can be seen as an instrument made by a virtuoso performer. Virtuosity is difficult to define though, as we will see in a later chapter. However, there is a limited (but growing) group of instrument designers who play self-made instruments and systems on a professional stage and we argue that their mastery is defined by the context in which they operate. These peer 'performing instrument designers' (PIDs) participated in open qualitative interviews to form an overview of the practice and opinions that informed their design processes. (See Appendix A). The expectation was to find some sort of 'PID' pattern of overlapping practice and opinions that would help non-'PID' designers in their design efforts.

Although the Electrumpet was intended as an example instrument right from the start of the study, it changed completely over the course of it. Firstly, there was stagnation in its development, which had been continuous up to then, then additional insights from interviews and the practice exposed a fundamental design weakness and finally a design insight breakthrough resulted in a completely new software system that was largely based on and inspired by insights from the interviews. This changed the Electrumpet's position from just one example instrument to the ideal case study for the implementation of the model.

Taking the Electrumpet as a case study, this thesis describes how a model conceived through interviews with 'PID' designers can inform instrument designers in improving their instrument designs.

1.1 What is the Electrumpet?

In technical terms, the instrument is a so-called hyper instrument (Machover, 1992); an instrument that combines an acoustic instrument with an electronic extension. Other examples are the hyper flute designed by Cléo Palacio-Quentin (Palacio-quintin, 2008), the mutantrumpet by Ben Neill (Neill, 1992) and several trumpets designed by Sukandar Kartadinata (Kartadinata, 2003). The definition of these instruments does not describe their function. Hyper instruments have been designed with different motivations and use contexts in mind. I see the Electrumpet as a system designed around the acoustic trumpet that enhances the possibilities of the instrument, allowing it to take on musical roles not traditionally associated with a brass instrument. These musical roles are

designed around my personal taste and musical context, allowing me to operate within these contexts using a very unique voice.

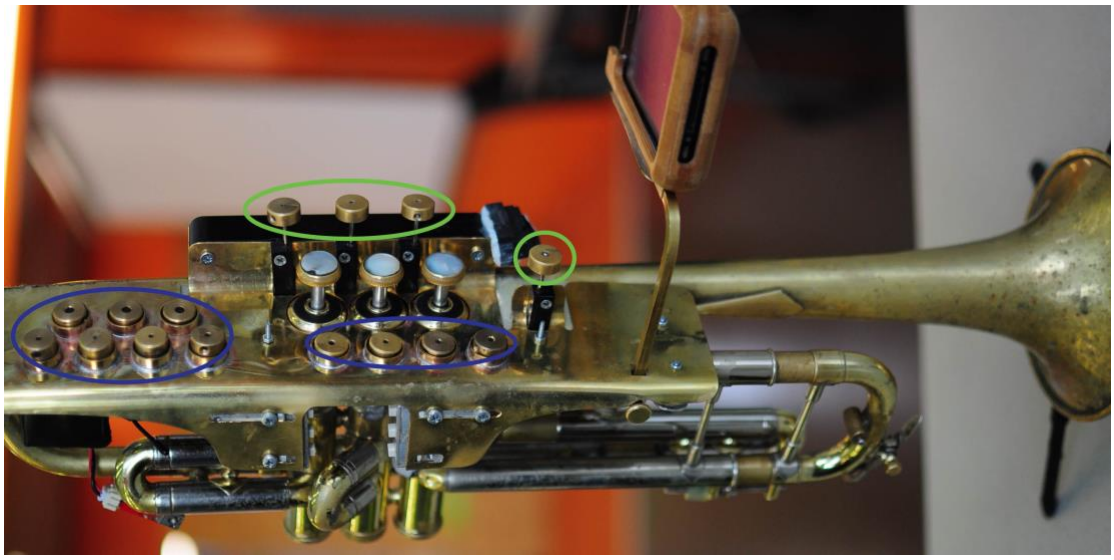


Figure 1 The Electrumpet (old model)

The picture provided on this page is deceptive and tells little about the implementation of the knobs that are visible. It does not tell that the knobs circled in blue were intensively used a year ago, but have now been completely discarded in the new physical Electrumpet design. The knobs circled in green (which have a similar feel and action to normal trumpet valves) were almost never used and on the brink of being removed, but are now among the most intensively used sensors. These changes are the direct fruit of the conclusions of this PhD research and will be more extensively discussed in chapter 5.

The knobs and other sensors on the Electrumpet are connected to a system in the computer that can manipulate the acoustic sound of the trumpet in real time. This system implements sound processing techniques, while also organising the material in time and pitch/frequency. The sensors on the Electrumpet are mapped to the system. The knobs circled in green have been given a new functionality and are completely responsible for moving through the organisation of the system between different 'discreet states'. Some of the other sensors on the instrument are used to manipulate sound and material organisation within such a 'state'. Chapter 6 contains a further technical description of the Electrumpet system, and discusses in particular how its design was transformed - technologically, musically and conceptually - by the PhD research.

The development of the Electrumpet is an ongoing process that will not end with the submission of this thesis. Although late in the process, a huge step has been made in the improvement of the instrument and, more importantly, in its potential for future development. The music that can be made with the instrument has matured and its sound has gained a professional quality.

This thesis not only describes the process but also the construction of a design model that was used to improve the instrument. The construction of this model

has only been possible through the participation of ten of my colleagues who offered their valuable insights in lengthy interviews and the professional guidance of my supervisor professor Pierre Alexandre Tremblay. It is my hope that other instrument designers can benefit from and build upon this work in designing or improving their own instruments.

1.2 Thesis overview:

In the second chapter of this thesis, we will first discuss the professional musical context in which the Electrumpet was conceived and will continue to be used after the PhD. This chapter will provide us with design positions and requirements originating in this context that will have to be fulfilled. In chapter 3 we will introduce the 'persona model for musical instrument design' (PM_MID) and the seven personas we have defined, explicating how the model was constructed on the basis of qualitative interviews with PIDs. In chapter 4 we first discuss virtuosity in relation to newly developed musical instruments and subsequently the model is cross-examined against *Second Order Virtuosity*; a term proposed by the trio Brachiale to define virtuosity in relation to new musical instruments. Chapter 5 is an analysis of the state of the Electrumpet before and after the PhD-driven research and its implementation. Persona values that have driven the design decisions are named and related to the actual implementations. Chapter 6 describes the new Electrumpet system in its conceptual and technical details, with an emphasis on 'smart control through musical phrase association'. This concept formed the main design breakthrough during this PhD period. Chapter 7 describes how composition strategies are implemented on the instrument, especially in relation to improvisation in different contexts, and attention is also paid to the development of virtuosity through structured tinkering and improvisation and through simple etudes for improvisation skills. We conclude with a chapter recapping the benefits of PM_MID for the design of the Electrumpet, expanding it in relation to a discussion on instrument design in general and the possible usability of the model in relation to the NIME community.

Chapter 2 The Electrumpet before the PhD

Section 1.3 introduced the Electrumpet and briefly discussed its relation to the PhD. The instrument had a history before the PhD period though and will continue to have a professional life after this submission. Before the PhD, the Electrumpet was being used more and more in professional musical practice and it will continue in this context after the PhD and into the future. The main motivation for the PhD was to boost development of the instrument, professionalization and development of depth.

2.1 The Electrumpet in the context of earlier artistic work:

When the Electrumpet was first presented at the 2009 NIME conference in Pittsburgh, the presentation opened with some musical fragments from earlier ensemble work (the designer of the Electrumpet being the artistic leader of said ensemble). There was praise for that particular aspect of the presentation as it was a novel approach in a mostly technical conference; new instruments are not just new instruments in their own right; they are born in a certain personal and musical context that also determines their further development.

This chapter discusses the author's early experiences with live electronics, the musical context in which the Electrumpet was conceived and experiences with the Electrumpet before the PhD. The influences these experiences had on the development and vision of the instrument's operating space are discussed.

2.1.1 Early experiences using live electronics:

Before the development of the Electrumpet, which started in 2006 and got serious in 2008, there was already some experience with live electronics on the unaltered acoustic trumpet and also some experience with live electronics in the context of the Electrumpet designer's band: Tetzepi (Leeuw, 1997)

The first experience with live electronic music dates from 2000, when Tetzepi did a project with Edwin van der Heide. Edwin was part of the Sensorband project (Tanaka, 2000) and worked with the MIDI-conductor, an instrument (Bongers, 1998, pp. 16–17) that was similar to "the hands"; the instrument invented by Michel Waiszvisz of STEIM (Krefeld, 1990).

Working with Edwin was a first glimpse into the possibilities of manipulated digital sound; granular synthesis on a single buffer in this case. The cooperation with Edwin was a one-off project that resulted in a small tour, a radio performance and a CD recording. The pieces were written around him and the possibilities of his instrument.

The potential of live electronics for musical practice had become clear. A year later, Herautronique, a duo with Jorrit Tamminga, a colleague at the University of the Arts Utrecht, was formed. This duo explored the potential of live electronics and acoustic trumpet. The project lasted till 2006 and the wish to independently manipulate electronics as a trumpet player grew.

Some experiments using foot controls followed, but they were unsatisfactory, mainly because attention wavered between the controls and the trumpet. It was

one of the incentives that led to the development of a controller on the trumpet itself.

2.1.2 Tetzepi and the Electrumpet:

The projects with Edwin van der Heide and Jorrit Tamminga were not extreme outliers in an otherwise mainstream context. The main artistic practice was the artistic leadership, from 1997 onwards, of a Dutch avant-garde big band that only played original repertoire (Leeuw, 1997). The band implemented a broad repertoire ranging from conduction and game pieces (Matrix, Hans Leeuw, 2001). to written-out pieces implementing complex grooves that merged Carnatic rhythm development (Reina, 2015) with modal jazz harmony (Paradiso, Hans Leeuw, 2008). Tetzepi ("Tetzepi," 2011a) was a band that united recently graduated conservatory students of jazz music with a preference for an experimental approach; hence also the collaboration with Edwin van der Heide.

Tetzepi was part of a newer generation of bands in this tradition. Rather than being a purely artistic vehicle for the artistic leader, it was much more of a collective, with the intention of performing new work from composers writing especially for the jazz and improvised music scene. Most works performed by the band were a mix of ethnic styles, often with complex rhythms and always partly or mainly improvised. The improvisations varied from, mostly collective, free improvisation reminiscent of the music improvisation company (Bailey, 1992, pp. 94–97) to improvisation within constraints in an adapted form of Zorn's game piece cobra (Van der Schyff, 2013) or conduction in the tradition of Butch Morris (Morris, 2006) as well as the traditional soloist with rhythm section backing. Improvisation was both idiomatic and non-idiomatic (Bailey, 1992, p. xi). The band also experimented with improvisation using self-designed game pieces. A host of composers have written for the band, with most composers writing more than one piece. The band leader and some of the band members were part of the writers collective as well.

Within the context of Tetzepi, the Electrumpet found a rich environment for experimentation and the instrument was used within the band almost immediately after its invention in 2008. Within the band, the instrument was used in about a third of the pieces, mostly in particular sections (Break? Dance!, Jorrit Dijkstra, 2013). However, the number of interactions and sound possibilities implemented was limited, and when the band had to stop in 2014 due to funding problems, it was also an opportunity to invest in the versatility and further development of the instrument. The plan is to reanimate the band in the near future in a different format with the implementation of interactive electronics on a smaller number of horns (Tetzepi had 3 trumpets, 3 trombones and 4 saxophones). The development of the Electrumpet within the PhD, but also the development of etudes and other strategies for learning to master a hyper instrument, can be seen as part of that process.

The author always found a powerful attraction in the big band in its ability to have large complex chords that range over the whole auditory spectrum. Using electronics on three acoustic horns could at least mimic the power of a large big band. Mastering the technical difficulties in creating the effect of extra horns and

the versatility of the horn section is one of the goals behind the Electrumpet development.

Different forms of free, guided and collective improvisation were explored within the band and one of the band's special strengths was to juxtapose completely free playing with highly organised rhythmically and harmonically complex fragments. The Electrumpet was mostly used in free improvisations. It should be noted that the Electrumpet's effect repertoire was still limited when Tetzepi stopped in 2014, as was the virtuosic control over the existing versatility.

So, for the musical practice of the Electrumpet within Tetzepi, there were musical requirements connected to free improvisation to requirements connected to complex and timed harmonic situations.

2.1.3 Other musical practice influencing the Electrumpet development:

Though the musical practice within Tetzepi was broad, modern and experimental, at its base almost all musicians were trained as Jazz musicians. The Dutch Jazz scene had quite a few players that approached mainstream Jazz in an unorthodox manner. During weekly jazz sessions in 'Café the Engelbewaarder' one such player, Sean Bergin, was very proficient in navigating between the free jazz that made Dutch Jazz famous and the much more traditional music of his home country South Africa (Whitehead, 1998). At first it was strange that his autodidact raw tone and many 'mistakes' were attracting so much attention, but later this wonder turned into appreciation for his devotion to telling a story while embracing his 'educational handicap'. Bergin made clear how strong the development of a personal voice can be in music.

This also has bearing on the musical and interaction decisions for the Electrumpet. Ultimately, the Electrumpet should afford for telling stories in the different musical environments in which it operates and it should do this with affordance for the physical relation between player and instrument that was so audible, visible and tangible in the playing of Sean Bergin. For me, he is an emblematic example of 'Expressivity/Effort/Corporeality'; one of the criteria for instrumentality (Hardjowirogo, 2016, p. 20) mentioned in the introduction.

2.1.4 The musical practice of others that influenced the Electrumpet:

Edwin van der Heide (Tanaka, 2000) was already mentioned as a positive inspiration, although he did not play an acoustic instrument. When watching and listening to several colleagues using acoustic instruments, brass and wind in particular, I was not too impressed with the results. Often, they utilised the use of foot controls or even loose hand controllers with live electronics. There was no real integration.

The only person at that time who did seem to have an expressive involvement with live electronics and an acoustic instrument (flute) was Anne la Berge. She is also one of the interviewed experts for this thesis. She uses foot controls to control her effects but her main expressive tool is the microphone.

There are of course many more examples of instrumentalists using live electronics. Before seeing Anne perform, though, the author was only familiar

with instrumentalists who used ready-made effect racks with little interaction and engagement with the electronics, other than on/off. Completely electronic instruments like the EVI and EWI (Steiner, 2004) that were also observed detracted so much from the expressive and acoustic possibilities of acoustic instruments that they were deemed less interesting artistically.

The expressive qualities seen in the use of live electronics of Anne la Berge and Edwin van der Heide were an inspiration, and at the same time there was a growing resentment against the inexpressive use of ready-made live electronics.

2.1.5 Musical practice with the Electrumpet that influenced the instrument:

After the Electrumpet was developed in 2008, it was not only an instrument within the Tetzepi Big Band, but also a new opportunity to perform. There were all sorts of performances. The Electrumpet was not intended to function purely within the electroacoustic context. It functioned within many improvisation evenings at 'Zaal 100, Amsterdam' as part of an artistic collective in which Tetzepi participated and was performed more generally in the Netherlands. The instrument was also used in Jazz jam sessions.

In 2012 a cooperation started with Diemo Schwarz, who plays his own software system, CataRT (Schwarz, Beller, Verbrugghe, & Britton, 2006). The duo practices pure improvisation. The trumpet sound is manipulated on both the Electrumpet and within the CataRT system. The CataRT system also uses the pre-manipulated sound of the Electrumpet. There is no real style border but the focus of the improvisations is always sound. Rhythm and melody may arise, but this is not an aim. In both the duo with Diemo and while playing with the occasional live electronics user, they often request not to use recorded layers. Within Tetzepi this global space of sound also had to be negotiated.

All these experiences influenced the sound and chosen operating space of the Electrumpet. The time scale of musical actions that is explored is almost exclusively about 10s long at most and the resulting sounds are mainly local in nature (Emmerson, 2007, pp. 92–103). The low register is used sparingly, following several complaints from low register players. The instrumentation of the trumpet sound has become a topic that was not consciously thought of before. Current sound design decisions are optimised to create space for other musicians to operate in.

2.2 The conception of the Electrumpet

2.2.1 Hardware implementation

A first version of the instrument was tried out in 2006 in a student project. It never materialised into a 'real' instrument, but some concepts that later returned in the Electrumpet were already tried out. The compact and unobtrusive character of the augmentation, plus the opportunity to reach the augmentations easily from the normal playing position, were already part of the original design.

At the end of 2007, a first real version was built in a period of about three months. This (hardware) version served till 2011. A new version built in the same year was sturdier, had a few more knobs and was more hushed (the knobs

were pressure sensors), and the wireless protocol changed from Bluetooth to XBEE, which reduced latency and latency jitter. This hardware version is still in use, with some improvements made before and during the PhD, though not fundamental ones.

Hardware version 3.0 has become part of the PhD project though. In chapter 5 the upgrades in both hard- and software are discussed in relation to the persona model.

2.2.2 Software:

Over the years the software implemented on the instrument (always written in MAX) improved, but some things stayed the same for a long time. A strategy to use four buffers for sound processing as the base of the system has been in place from the beginning until 2017. Over time the quality of the sound and the efficiency of the playing patch improved. This was sometimes instigated by new software developed, in particular, by IRCAM.

The use of FTM&Co (Schnell, Borghesi, Schwarz, Bevilacqua, & Muller, 2005), in particular, has shaped the system approach within the Electrumpet software. The opportunity to think in data objects, rather than the virtual data streams in plain MAX, has influenced the thinking paradigm. Gabor (Schnell & Schwarz, 2005), which is part of FTM&Co, can pick sound matrices from the audio stream that can then be manipulated as data. Choosing tools may seem to be a matter of choosing the right tool for the right job, but it can also be choosing the right tool for the right person. We are familiar with the choice between graphical programming languages (e.g. MAX, Reactor) and text-based programming languages (e.g. Supercollider, chuck), but choosing tools within those languages is a second layer of personal choice.

Other tools that operate in the MAX programming environment and were used on the Electrumpet are tools from CNMAT, Berkeley, especially the OSC messaging system (Wright, 2005) and within the PhD, the Bach Suite for computer-aided composition (Agostini & Ghisi, 2013), the tools of Alexander Harker (Harker, 2011) and another host of tools developed by IRCAM: SuperVP, MUBU, Spat, FTM&Co. (Ircam, 1998)

2.2.3 Development overall:

The development of the Electrumpet since 2008 was not continuous. There have been periods that the instrument stayed the same for a while. Periods of hardware development alternated with periods of software development and periods of practice. Mostly the work was (and still is) divided into blocks of one to four months dedicated to a certain (new) feature or activity. Winning the Guthman competition for new instruments in 2013 was an important milestone, but also a time for reflection. This PhD is an attempt to create depth and put the Electrumpet in a broader perspective of new instrument development.

2.3 The Electrumpet in relation to the NIME discourse:

The PhD thesis is not the first dissemination of the lessons learned with the Electrumpet. The instrument had unique features and was interesting for the NIME community (NIME Community, 2001), (Leeuw, 2009), (Leeuw, 2012). The high-level musicianship combined with the ability to fully design the instrument in both hardware and software made for a unique designer position as well.

The NIME community is of particular interest to designers interested in the latest techniques that could be implemented on new instruments. For the Electrumpet, the implementation of new wireless technology (Fléty & Maestracci, 2011) (Mitchell et al., 2014) and DIY pressure sensors (Freed, 2008) were a direct result of NIME visits.

The NIME conference is also a festival for new music performed with these new instruments. The conference is mainly focused on the design of new instruments but it acknowledges the practice as well:

> 'The International Conference on New Interfaces for Musical Expression gathers researchers and musicians from all over the world to share their knowledge and late-breaking work on new musical interface design.'

In the early years of the conference, new technologies could be presented in the context of instruments that would then never be seen again. As of late, however, there are more examples of instruments or technology that were first presented at the conference and then later made it to the market. One of the first instruments to do so was the Reactable (Jordà, Kaltenbrunner, Geiger, & Alonso, 2006). In a keynote speech to the community, one of the inventors of the Reactable, Sergi Jordà (Jordà, 2011), was critical about the fact that the reviewers hailed the invention of the Reactable but rejected the papers about the subsequent iterative improvements. As of late, there are more serious companies built around technology and instruments originally presented at NIME: (Lamb & Robertson, 2011), (McPherson, 2012)

While the conference acknowledges the practice, this does not mean that a lot has been written on the practice of new interfaces. The issue was brought forward in 2006 when the conference was in its sixth year (Dobrian & Kop, 2006). Since Dobrian's conclusion has been very important as a starting point for the PhD, it is quoted here:

> "If musical expression with new computer interfaces is to reach the level of sophistication achieved by major artists in other specialties (jazz, classical, etc), it will be necessary to encourage further development in the following areas: continued focused research on strategies for better mapping, gesture recognition, and feedback; dedicated participation by virtuosi (utilizing existing virtuosity and developing new virtuosity); repertoire development for—and multiple performances with—a given instrument as a way to further its development; and more opportunities for critical discourse, both within the community of practitioners and among non-practitioners."

It is hard to objectively determine whether researchers within the NIME community took all of Dobrian's words seriously in their own practice. Discussions in later NIMEs and workshops preceding NIME have indicated that at least part of the community still thinks that at least the dedicated participation by virtuosi is an issue. Cléo Palacio-Quentin wrote a paper for the community about her practice with the instrument in 2008, although she also has a hard time discussing this in musical terms (Leeuw, 2017)

The NIME community and the community around the practice are the most important anchors for the development of the Electrumpet. The lessons taken from the PhD will be applied in an improved musical practice and will be disseminated in the wider NIME community.

Chapter 3 The persona model for musical instrument design:

3.1 Introduction:

In the previous chapter we set out the context in which the Electrumpet was conceived and discussed its history. We learned that the context in which the instrument was used played an important role in its original development. The original PhD premise was that this context could be generalised to the context of 'the professional (virtuoso) musician turned instrument developer'. What specific insights do these musicians bring to the table that non-musicians and amateurs don't and could we describe these insights in such a way that they are useful to non-musicians who design instruments?

Behind this premise was the idea that there would be some sort of archetypical musicians' view on instrument design. While interviewing 'professional (virtuoso) musicians turned instrument developer' the idea of an archetype was abolished. Quite a few remarks on instrument design are shared among the group but the diversity of remarks and viewpoints was much more important in driving design decisions. Instead of looking for an archetypical 'musician turned instrument developer', the search was directed at a model that could encompass all the different viewpoints and be useable to capture professional performer insight. The model describes each instrument designer as a make-up of seven different personas: Performer, Instrumentalist, Luthier, Improviser, Tinkerer, Composer and Designer.

After defining those personas, the new question to be answered in chapter 5 is whether the 'Persona Model for Musical Instrument Design' is helpful for the analysis, the subsequent redesign and the appreciation of that redesign concerning an electroacoustic musical instrument and in particular a hyper instrument.

Chapter 3.2 describes the model and the personas involved. In chapter 4 the model is discussed in relation to *'Second Order Virtuosity'*. In chapter 5 the model is used to evaluate the Electrumpet itself and is brought in relation to its improvement. A description of the methodology that led to the model can be found in chapter 3.3.

3.2 The persona model for instrument design:

Personas are used in design practice to segment groups of users of products (Jenkinson, 1994). In our case we turn this around and define our personas as archetypes of makers that inhibit certain characteristics. The personas are as narrowly defined as possible. A real person will therefore always be a complement of diverse personas and will at different stages in the design process take on different personas or roles. Another synonym would be attitude. A professional musician on stage takes on the performer attitude.

Our personas come with a value system (Iversen, Halskov, & Leong, 2013). People who identify strongly with one persona will probably have strong value systems, but not necessarily the same value system as another person that identifies with the same persona. For the purpose of instrument design, we are interested in the values associated with the personas, as they are often a driving force behind the design process, and also in the conflicting insights that different personas can provide.

The values of a persona do not only reflect on activities executed by the persona but also, and importantly, on requirements from other personas with different expertise. Later on, for example, we will discuss the importance of personal voice for the performer persona. From the composer persona, the performer would want a piece that fits the persona and lets it shine; from the Luthier, the performer would want a sound that matches, and from the designer a system that does not block the personal expression.

Personas have positive and negative sides to them. A persona can view the design of the musical instrument based on the experience and expertise from the related field and use the tools of the field to improve the quality of the instrument. Personas also have the dogmas and biases that belong to the associated field, which can hinder new methodology or otherwise creative solutions. When one of the personas is dominant, there is the risk that the importance of the associated field gets overemphasised in relation to the fields of other personas. It is assumed that an honest and personal analysis of each persona will lead to better design.

Deliberately adopting the position of each of these personas during the design process of a musical instrument can unearth aspects of the design not yet contemplated.

The descriptions of the diverse personas are deliberately formulated in a schematic fashion. A persona might have a slightly narrower description than what the reader is used to. The complexity of real instrument design is sought in the combination of the personas and not in the subtleties of each individual persona.

The personas should function in a similar fashion as the ‘six thinking hats’ of de Bono (De Bono, 2017). The personas can be used in discussions about instrument design, for brainstorming and for evaluation and reflection.

The seven personas that every instrument builder (or team of builders) should consider.

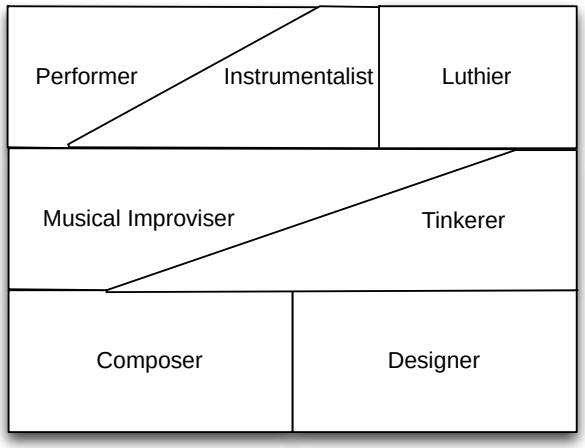


Figure 2 Persona Model

3.2.1 Performer:

The performer persona as it is meant in this diagram (each persona described here is meant as the persona in the diagram and not as a generic description) concerns the overall awareness and skill of being on stage performing before an audience. This involves a wide range of practical and mental skills, the necessary experience for giving the optimal performance in the given circumstances and, if applicable, also the ability to adapt. From the seven criteria of Sarah-Indriyati Hardjowirogo (Hardjowirogo, 2016) for instrumentality the last three are relevant here: Expressivity/Effort/Corporeality, "Immaterial Features"/Cultural Embeddedness, Audience Perception/Liveness

3.2.2 Instrumentalist:

The instrumentalist persona concerns the instrumentalist in the classical sense of the word. It involves the aspects of dexterity and fine control, and their mastery. The typical instrumentalist emphasises the ergonomic and responsive aspects of the instrument in the physical and interactive design and the controllability of the total system. From the seven criteria of Sarah-Indriyati Hardjowirogo (Hardjowirogo, 2016) for instrumentality the first four are relevant here: Sound Production, Intention/Purpose, Learnability/Virtuosity, Playability/Control/Immediacy/Agency/Interaction.

A less graspable but still important aspect of the instrumentalist persona is the relationship to the instrument. According to Fels (Fels, 2000) a 'highly intimate relationship' with the instrument is needed for 'high skilled performance'.

3.2.3 Luthier:

The luthier in this diagram is much more than the violin builder that is traditionally associated with the term. There are still mechanical aspects to concern, but that has been augmented with 'sensor knowledge' and 'connection knowledge' (e.g. wireless). The knowledge of digital or analogue sound processing has become a core competency of the luthier persona, and a task previously assigned to the sound engineer concerning placement and other 'live

postproduction' tasks is also part of the skills portfolio. Even the instrumentation task is shared between the composer and Luthier personas. Sergi Jorda coined the term 'digital Luthier' in his thesis. His definition is wider than the one we use here and includes the designer persona (Jordà, 2005).

3.2.4 Musical improviser:

Describing musical improvisation is sort of an oxymoron, according to Bailey: 'there is something central to the spirit of voluntary improvisation which is opposed to the aims and contradicts the idea of documentation' (Bailey, 1992, p. ix). Depending on the context (musical style) in which improvisation is used, there could be different aspects of importance (once again according to Bailey). The most important aspect in which improvisation is used in the diagram is the musical exploration of the instrument by experiment. This exploration can be a solo venture but can also be in relation to other instrumentalists.
The exploration can be a form of building the instrument on stage. In that case the border between the improviser persona and the tinkerer persona (the next entry) will blur or vanish completely (live patching analogue synths, live patching digital modules, live coding etcetera).
The exploration aspect of the instrument can also be there by design, by introducing unpredictability, for example.
If the instrument is designed for improvisation (another oxymoron), then aspects that could be of special concern are the range of available content, the functionality of that content in relation to other musicians, the ability to retrieve that content quickly on demand (Pluta, 2012) and the learnability of the scope of the instrument; the latter possibly with the accompaniment of some learning methodology for the instrument.

3.2.5 Tinkerer:

The tinkerer persona concerns the more classical 'hacker type' of instrument builder but also the musicians that patch their instruments in an iterative fashion. For example, when Ableton Live was built it was a design, but certain musicians that build their instruments nowadays using Ableton Live are tinkerers. Designing an analogue module is designing, but patching modules together is tinkering. Tinkering can be seen as a form of designing (Resnick, Myers, Nakakoji, Shneiderman, & Pausch, 2005, p. 10). A programming environment like MAX allows for both design and tinkering.
Just as with freer forms of improvisation, it is difficult to describe 'methods' of tinkering. A good tinkerer tries out lots of alternatives and is guided by the process rather than the plan.

3.2.6 Composer:

The composer persona as it is meant here is narrowly defined. Here we mean a person that plans in a top-down manner: "This is the (sounding) artistic result that I am aiming for and I need this and this to happen in order to get there". The composer persona is responsible for the organisation of sounding material in time but also of musical material in relation to other musical material.
The composer persona can take complete responsibility for all the details in a composition, but can also leave the task (or part of it) to the improviser or to a

process that generates musical material. However, the composer is the persona with the plan.
Composition is not only done 'for' the instrument but can also be done 'from' the instrument. In some cases, the composition and the instrument are one and the same, but all kinds of hybrid forms can exist.

3.2.7 Designer:
The designer persona as it is meant in this diagram takes a planned approach to instrument design and has a multidisciplinary approach. Knowledge from neurology, psychology and other relevant scientific fields is incorporated in the design of the musical instrument. A designer is concerned with getting as complete a picture as possible of the design process, and this very model of personas is an example of a tool that can help the designer. Unlike the tinkerer, the designer does not immediately start building an instrument based on a hunch, but tries to have a very clear idea of the requirements from as many perspectives as possible (for what?, for whom?, why?, etcetera). Although experiments and mock-ups, etcetera, play an important role in this process, they are intended as research for the design or the next iteration of it.
Furthermore, the designer is also the persona that guides the whole process reminiscent of the blue hat in the De Bono system (De Bono, 2017, pp. 146–172).

3.3 The axes of the persona diagram:
The personas occupy a specific place in the diagram based on two axes. One axis represents the object aspects versus the time-related aspects of sound, music and composition. The other axis represents three levels of working: conceptual, experimenting and practising. The axes are qualitative in nature and do not represent absolute values. The two axes give another view on the 'conflict' between the diverse personas, and anchor their roles in a structural whole. It also helps to provide a clearer definition of the meaning of the personas within their boundaries within the model.

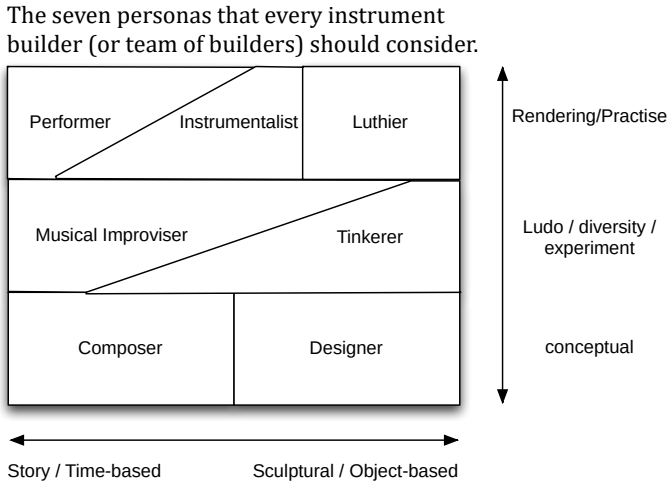


Figure 3 Persona model including axes

3.3.1 Left / Right:
If we move on the horizontal axis from the right to the left, we move from the sculptural to the story representation or from a static object to a narrative in

time. Personas on the right side of the diagram are involved with making the object and personas on the left with making the musical story. The sloping line between tinkerer and musical improviser indicates that the border between the two personas is not sharp as with some other personas. We can imagine a feedback process where the musician / instrument builder sits in the studio, plays a little on the instrument, listens, changes the instrument based on what is heard and plays again, etcetera.
Something similar can be said about the instrumentalist and the performer. The instrumentalist is not absent on stage, while at the same time a professional instrumentalist will always play imagining the performer role.
This axis is not discrete, with the right half being purely object-minded and the left purely music-minded. There is a transition between the two. Think of sound designing the instrument. No sound can exist without a time component in it. If we go from right to left, however, the time scope increases, with the left standing for complete concerts or compositions and the right for the instrument as an object and sound as an unmoving continuous static wave.

3.3.2 Top / Down:
Moving up and down the vertical axis, we pass through different levels of engagement with the instruments' design and music. These levels of engagement are defined in the following paragraphs.

Practice / rendering level:
Skill is the core value at this level. This is not the level of creativity, but rather the level that uses existing knowledge and experience to get to a 'finished product'. This can be the synthesis of the performance or the instrument, but also a state of complete mastery of a musical instrument through practice within a certain context. The personas on this level are reminiscent of the traditional trades that evolve slowly but steadily over time and were taught through the master/apprentice model that uses slow-moving knowledge transfer. In his book 'The World Beyond Your Head', philosopher Matthew Crawford describes the value of the manual mastery involved in these trades in today's society (Crawford, 2016, pp. 133–135). The acquisition of new skills is a process of reflection and problem-solving in the quest for perfection.
Skill is often built through repetition: the performer carrying out the 'performance ritual', the instrumentalist repeating etudes and exercises, or the Luthier building instrument after instrument. Variation exists but drastic changes are more often associated with the personas on the other levels.
It does not mean that personas that identify with other levels do not use repetition of tasks. The practising composer (not the persona) works from a conceptual idea, but needs a lot of craftsmanship skills to synthesise the concept into a final composition.

LUDO, experimentation level:
It could be argued that experimentation is always part of design, and the iterative design process would include the tinkerer persona and some forms of improvisation. There is a clear difference, however, if the product is an adaptable musical instrument and it is about the music made with it. The tinkerer phase is not a phase in the route to a finished product, as would normally be the case in

other types of products, but it is a phase in a continually evolving, changing and transforming product that is never finished. If we still want to put it in design terms, it could be framed as open-ended design (not to be confused with open-ended design problems) a term that is used especially in relation to interaction design for free play involving children. (Creighton, 2010, pp. 178–180)

Conceptual level:
The concept is the core value at this level. Originality or the ability to come up with things that had not been thought of before are typical strengths needed of persons that operate at this level. However, we should not forget the ability to transform ideas into concepts and the ability to sublimate concepts from requirements or fields of ideas.

3.4 Methodology, justification of the model:

The last section introduced and explained 'the persona model for instrument design'. This chapter will discuss the conception of and bases for the model. The model is descriptive and should not be seen as a recipe for making perfect musical instruments but rather as a tool for conception, evaluation and discussion.

The original question at the start of the PhD was: "How does instrumental virtuosity influence the design of new musical instruments?" The hypothesis was that there was one ideal common ground among musical performers that could be described. This premise had its origin in informal talks with fellow musicians in the world of instrument design and electroacoustic music. Sam Pluta put it quite bluntly in his interview (Appendix A.1), but his sentiment was well recognised by other professional musicians familiar with the 'NIME community':

> "… you have these very well-meaning engineers who have never made music before trying to do something and it's like well you're totally missing the bases of music… they'll miss like some huge thing that any musician would just like, you know, 'red lights would flash' …So I think partially that that maybe it is like a combination of music background and engineering background."

It seemed worthwhile to distil musical knowledge usable in the course of designing a professional musical instrument, so that that community of technologists could benefit from it.

'NIME' literature on new musical instruments focuses mainly on the instrument, and the person of the designer is not discussed. For the main part, the musical context of the designer is discussed in very specific cases, when the designer is also the performer (Palacio-quintin, 2008), when it is an instrument for a specific ethno musical context (Trail, Tavares, Godlovitch, & Tzanetakis, 2012), (Burtner, 2004) and mostly when the instrument is used in the context of specific pieces. Hardjowirogo (Hardjowirogo, 2016, p. 21) says:
'an instrument's identity cannot be fully understood without studying the cultural contexts in which it is embedded. Despite this being a key issue in ethnomusicology, as is impressively demonstrated, e.g., by Kartomi (1990), still it is all too often forgotten in the study of contemporary musical instruments..

The absence of a thorough analysis of the instrument builder's background when discussing its design is an omission, since the designer of a musical instrument is per definition biased by (musical) background, context and taste, which will be reflected in the instrument designed.

The research hypothesis was that the skill set that performers acquire through years of studying and performing and that they unconsciously or consciously use while designing an instrument could be distilled in knowledge useable for 'non-musicians' within the NIME community. The transfer of knowledge and skills from playing an acoustic instrument could be particularly interesting, as this knowledge and these skills are often acquired within the context of a centuries-old tradition of musical virtuosity.

The research would then lead to an instrument model comparable to that described by Luc Nijs (Nijs, Lesaffre, & Leman, 2009, p. 132), which was explained as follows:

> 'Although the body of literature on the performers' instrumental and expressive gestures is growing, far less has been written on the musical instrument as an extension of the human body. The latter is considered to be the most natural mediator between subjective experience and physical reality. This extension can become natural, i.e. part of the body, as a result of several processes. Research is needed to address these processes and the way in which the musical instrument influences both the construction and communication of musical meaning.'

Therefore, the original plan was to describe that subjective instrumental experience as a means to make informative design decisions. The idea to use musicianship expertise in the research of DMI's was not my own and is a continuous discussion within the NIME community. An article by Christopher Dobrian, called the 'E' in NIME, dealt with the issue of expression within the NIME community (Dobrian & Kop, 2006, p. 281). His conclusion read:

> 'If musical expression with new computer interfaces is to reach the level of sophistication achieved by major artists in other specialties (jazz, classical, etc), it will be necessary to encourage further development in the following areas: continued focused research on strategies for better mapping, gesture recognition, and feedback; dedicated participation by virtuosi (utilizing existing virtuosity and developing new virtuosity); repertoire development for—and multiple performances with—a given instrument as a way to further its development; and more opportunities for critical discourse, both within the community of practitioners and among non-practitioners.'

In informal conversations on the conference floor, often in review of one of the NIME concerts, and in various workshop sessions attended and given by the author (from 2008 onward), it seemed that the conclusion from this paper was still valid and had not been addressed properly in the body of papers. Musicians active in the field of electronic music are mainly in the minority at these conferences, but colleagues outside the conference endorsed Dobrian's conclusions in informal talks.

Nowadays there seems to be more movement, and a particular effort was made by Till Bovermann, Alberto de Campo, Hauke Egermann, Sarah Indriyati Hardjowirogo and Stefan Weinzierl, the editors of the book "Musical Instruments in the 21st Century: Identities, Configurations, Practices"(Bovermann, de Campo, Egermann, Hardjowirogo, & Weinzierl, 2016, p. 335). The book does not deal with the new instruments as such, but rather with the descriptions we need for their evaluation and the evaluation of their practice. The respective authors acknowledge their musical context:

> Trio Brachiale exists since 2010, when Dominik Hildebrand Marques Lopes, Hannes Hoelzl and Alberto de Campo first played together as a group at an evening with the Society for Nontrivial Pursuits in Berlin. We share much common ground, being performers, composers, coders, luthiers; and we are all inspired by second order cybernetics (von Foerster), observation of processes with nontrivial behavior, the possibilities arising from working with code, and the roles medieval and baroque combinatorics (A. Kircher, R. Llull) play for modern media-technological society (S. Zielinski). This makes the group an ideal platform for experimenting (Hildebrand, Lopes, Hoelzl, & Campo, 2016)

Interviews were conducted with participants that fit the description given by Dobrian in his article: 'One approach is to use sensor- equipped acoustic instruments or an interface modelled on an acoustic instrument to take advantage of the virtuosity already developed by experienced players. Another approach is for experienced performers to dedicate the time necessary to develop virtuosic mastery of a new interface.' (Dobrian & Kop, 2006, p. 280). The expectation was that these people would share a core "musicianship value" related to the embodied relationship they had with their instruments. Aware of a possible bias, the interviews were conducted in an open fashion though. Participants were asked to describe the history that led up to the 'invention' of their instrument and the relationship to their musical practice.

The first interview participants, who were both professionally educated musicians (flute and saxophone), would only partly associate their instrumentalist background to the design of their instruments. Cléo Palacio-Quentin positioned herself strongly as composer, while Sebastian Schiesser had taken on the role as instrument builder in a larger team. The social, cultural and musical position connected to their background seemed much more important in driving their design decisions then the seemingly objective instrumental criteria described by Cook (Cook, 2009a, pp. 218–220) and used within the NIME community. This became an important insight: what design positions were actually taken while designing the Electrumpet, and would different positions offer an opportunity for further improvement or at least evaluation?

Design positions are much more common ground in the field of participatory design. From participatory design we can learn the following: 'More importantly, PD is about negotiating values – a 'moral proposition' (Carroll and Rosson 2007) realized through participation.' (Iversen et al., 2013, p. 88). Since most of the people interviewed were both users and designers of their respective

instruments, the realisation emerged that musicians who design their own instruments deal with the same internal negotiation of values as teams in participatory design. Instead of looking for 'the instrumentalist outlook' the focus had now shifted towards the different values that 'musicians designing new instruments' negotiate within their design process.

Values can be very particular and very dependent on the personal context. A typical value-laden remark from Quentin: 'You know. I am a real performer. I play clubs with bad speakers. It is another reality.' (Appendix A.2). What is immediately apparent in this example and in many remarks from other participants is the importance of actually performing with the instrument on stage. There are also activities that Quentin rejects: 'I just don't want to spend time soldering cables' (Appendix A.2).

Values determine requirements in musical instrument making as they do in each design process, and whether a value is less or more important is dependent on the perspective taken when looking at the requirement. The chosen perspective is different from person to person, even in my highly curated shortlist of improvisational virtuosi. A perspective can change over time and depends on the lessons and experiences taken from playing and designing the instrument and other related activities like performing, practising and composing. A perspective does not come with an absolute set of values, but places the particular person in a certain position for analyses, comment, reflection and brainstorming, etcetera. Perspectives change over time and can even cross over from person to person, and in that respect, it is very insightful to compare the design path of two of my interview participants; the aforementioned Cléo Palacio-Quentin (Appendix A.2) and Sam Pluta (Appendix A.1).

- Quentin mentioned that she originally wanted to design an instrument that would have a multitude of sounds readily available: 'At first I was into, ok, I want to do free improv and then I want to have the control on all the parameters all the time and be able to turn of you know everything any time very fast, that was, the responsiveness was my issue like first'. So, here she chose the perspective of the instrumentalist persona.
- Later on, she came to the conclusion that she could not realise that and switched to a different strategy. She now developed patches that were connected to pieces: 'but then with electronics now my approach is now more compositional where I prefer to plan pieces and then I can develop different things and different ways of using the instrument'.

- Pluta was not a performer at all when he started developing the instrument he now plays. He started off as a composer: '... I didn't start doing music until college really so I started doing it in college and I started studying piano and I studied voice and then I was composing and I noticed that I was best at the composing… I guess in like being a creative musician I started as a composer and was writing notes on a page and when I went to Cap [note: university of Austin, Texas] with the master's program I started studying electronics… when I was there I started doing like you know bigger acousmatic(y) pieces and I was still writing notes on the page and I still

am and I was doing pieces that were like live electronics pieces where it is like you know cello and live electronics... so what I realised was that you know if I take the processes I was using for live processing and make them all available to me; at once I can kind of like improvise with. So that's when I first started improvising'.

- Then, the improvising becomes more and more a thing in its own right: '... it was like four of us on laptops doing live processing and then this jazz group. I kind of really loved it and I started focusing on that and I started writing pieces that I would call pieces but really they were me improvising and somebody else kind of having a composed improvisation where it is like okay now you're playing harmonics on the guitar and then you are playing glissandi like that kind of that was my score... if I can make it so that those could happen in any order then I could make a system that was improvised and could be essentially virtuosic...'.

Thus, Pluta ends with the situation that Quentin tried to accomplish in the beginning and vice versa. In essence, they swap their persona perspectives.

In participatory design the designer has to be aware that values colour the design process (Iversen et al., 2013, p. 95). The instrument designers that participated in the interviews could at times very clearly favour a certain role and certain positions. This is not necessarily negative. The colouring also arises from artistic positioning. It was the recognition of the artistic positioning that finally triggered the model presented here.

So, favouritism towards certain perspectives is certainly not a negative thing per se. It can lead to unique and interesting design choices. Knowing the perspective and living it will give you insights, automatisms and even instincts that people not familiar with the perspective will miss or deem less important. On the other hand, operating strongly from a certain perspective can also lead to prejudice against and superiority over other perspectives, missing aspects of other perspectives, and a certain kind of conservatism, depending on the perspective itself. This is where the persona model is very useful: allowing people to take a different perspective and keep challenging the biases taken in the design and practice of their instrument.

3.4.1 Iterative development of the persona model

The construction of the personas within the model was an iterative process. The original aim was to construct a diagram that took activities and perspectives of instrument designers as central to the construction of the model.

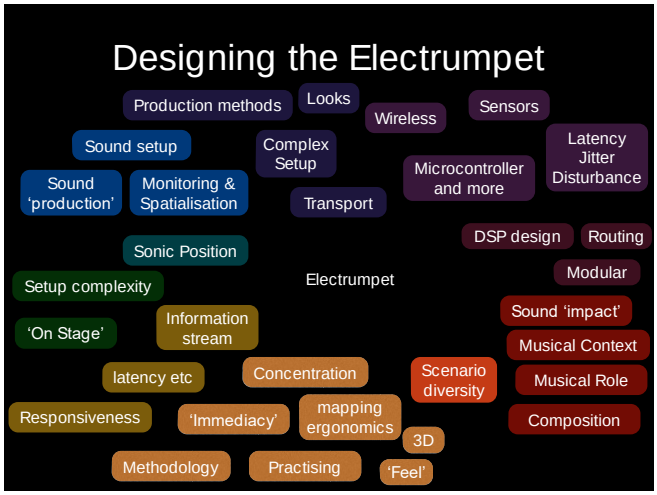


Figure 4 Activities and perspectives chart

The colouring was an initial attempt at grouping and there were no personas as of yet. It was the realisation that the interview participants often talked about specific roles while analysing the interviews that turned the collection of activities into personas. The above grouping was far from where we landed. There were a lot of entries that could be associated with the luthier persona although they were spread all over the chart. Some entrees can be attributed to the performer and instrumentalist and the improviser and tinkerer are absent. The designer is absent as well but arguably the persona making the map in the first place.

All the activities mentioned in the diagram are valid, but despite the grouping attempt, they show the designer as a mixed bag of insights.

Setting up a taxonomy (see Appendix B) for ordering the coded responses from the interviews helped. The upper level in the taxonomy contained four categories: 'making & doing' (remarks that described activities in design and making music), 'the self' (remarks that described background, opinions, personal & artistic preferences and relationship with the instrument), 'evaluative' (remarks concerning the development state of the instrument, the communication about it and comparison with other instruments) and 'about the interview itself'. The latter two categories are much smaller and we will not discuss them further.

It was tempting to try to make a direct relation between the remarks about 'the self' and the remarks about 'making & doing'. Some of the remarks of interview participants did mention that direct relation. Values-led participatory design, however, tells that such an approach is inherently flawed: 'the way we work with values means that they emerge in collaboration with stakeholders, with the values interacting recursively with the design process and permeating the entire process.' (Iversen et al., 2013, p. 90). In other words, the values are not fixed and can change over the course of the design process. This echoes the persona crossover between Pluta and Quentin discussed above. So, instead of trying to map the remarks on 'making & doing' and 'the self' onto each other, it is accepted that 'the self' and the values connected to 'the self' are constantly changing based

on experiences during the design process (which can span whole careers) and experiences from outside: music, technology and other fields.

Interview participants did refer to explicit roles during the interviews like: “I am a performer”, “I am a composer”, “I am an improviser”…. Most interesting, Schiesser (appendix A.9) referred to two distinct roles, musician and engineer, but did not mix them in his practice although he worked on the Sabre, a hyper bass clarinet, he did that purely as an engineer or the artisan and hardware electronics luthier persona (see 5.3.2 and 5.3.3). All the other roles were taken up by other people.
Sometimes the connection between design and (persona) position could be found directly in the interview, like here from Anne la Berge (appendix A.7): ‘I'm a very percussive player, I'm eh not a particularly lyrical player and I am someone who likes exploring the possibilities of noise. But the way I wanted to extend my instrument because I wanted it to be available as an instrument to play with other people is I spent a number of years only processing the flute in real time.’
Player is not one of the personas from the model. Here it could refer to instrumentalist, performer, and maybe improviser. La Berge also uses performer to identify herself. The next step was to identify value sets, which were subsequently called personas.

The personas were partly taken as explicitly mentioned in the interviews, such as performer, composer, and improviser. Partly, they were also constructed from the activities related to instrument design mentioned by the participants. The model was further refined, defining the axes and ultimately seven personas.

All personas are generalisations. The subdivision level was chosen for practical purposes and to be representative of the design perspective differences represented in the interview sample that consisted of professional (virtuoso) musicians very familiar with or active within instrument design. The Luthier persona, for example, could be further subdivided in sound specialist, electronics expert and instrument maker, but this would complicate the model rather than making it more transparent. That sub division is used in chapter 5 though.

The model in particular, but also the analyses done on the interviews for the model, led to a breakthrough in the re-design of the Electrumpet (chapter 6). The model is further used to analyse the instrument (chapter 5) and for a discussion on virtuosity (chapter 4).
A verification of the usefulness of the model in the design process of other new instruments has not yet been undertaken. In the next chapter, we will discuss the choice of seven different roles in more depth.

3.5 Why should there be seven personas to capture the scope of musical instrument design?

One could argue that the diagram could be brought back to four personas: instrumentalist (including performer), composer (including improviser), designer (including tinkerer) and Luthier or instrument builder. At one point it

was indeed simplified to these four entries, but was subsequently divided. In this section we explain why the extra personas have been split up in this way. The model's purpose is to help musical instrument design, providing it with distinctive personal/artistic perspectives from personas that are defined but not constricted by a value set determined by the activities associated with that persona.

The performer persona was the first major persona derived from the interviews and separated from the instrumentalist. Being on stage with the instrument and performing with it is the central starting point for all participants, except for Sebastien Schiesser who does not play the instrument himself; a fact that was not known when selecting interview participants (Schiesser did create his own hyper instrument before, but does not play it anymore and did not identify with it during the interview). It was not surprising that performance was central to the participants, as the author chose the participants on the basis of their expertise as performers.

The performer persona has specific relations with the other personas in the model that are not shared by the instrumentalist persona. Most participants saw an extra anxiety that was connected to being on stage with an instrument that could fail, do unexpected things or was in general complex. It would already start with packing the instrument at home, transporting it to the venue and setting up.

The improviser persona is not synonymous to an improviser. The personas in the model always stand in relation to instrument design. There is also no position taken in the sort of improvisation. It is on the instrument designer to define the desired relation between instrument design and improvisation. The improvisation capabilities that are sought in itself can be any of the forms Bailey describes in his standard work (Bailey, 1992) and beyond.
The changing perspectives on improvisation and composition between Quentin and Pluta, as discussed in the previous section, directly influenced the design and re-design of their respective instruments. It shows that both perspectives can be a vital aspect of the design and lead to essentially different instrument designs; especially in the way in which the 'instrument system' is organised. Pluta has written about instrument design specifically suited for the improvisation environment, in which he operates as a performer (Pluta, 2012).

The tinkerer was the last persona added to the diagram and the tinkerer persona was essentially 'recognised' because there was an empty spot within the diagram in search of viable axes. The tinkerer stands to the designer as the improviser to the composer. Tinkering in design is done in a certain phase of the design; the experimentation phase, the phase of mock-ups and concept development and of playing with ideas and material in a constructivist tradition.
It is also associated with science and technology learning. Tinkering is then a pleasurable way of experimenting to learn technology with a strong emphasis on 'play' or 'serious play'.
Electroacoustic instruments nowadays are often in a perpetual design state. In this respect, the design of an electroacoustic musical instrument is different from almost every other designed object, including traditional instruments. In the case

of the Electrumpet, the system of the instrument is a design activity. Filling up that system with content is done in an experimental and playful fashion: tinkering. The two activities have a different focus. Designer persona assignments could be to make the instrument suitable for tinkering and improvisation. (Resnick & Rosenbaum, 2013, pp. 163–181)

3.6 Usefulness of the model in relation to (different) instrument designers:

The reason for the model and the different roles is to gain insight into motivations for design. We can focus on the different roles and what they can offer us for the conception of our designs or for reflecting on them. Most importantly, the model can help us design instruments that are optimised for maximum versatility, if that is our aim.

It is important to note this last point: the subjectivity of our design goals. Practical reasons (time, knowledge, motivation, resources) have prompted most of the participants to make choices that limit their instrument-building efforts at different stages in their musical career. Favouring or discrediting certain personas involved in making design decisions does not necessarily mean that the interview participants have an objective or fixed position. Some interview participants see such limitations as a necessity for doing something at all, or see making very specific choices as part of their artistic profile.

> 'Because I have a limit.. a very limited time compared to people who are full-time electronic people.' (La Berge, Appendix A.7)
> That's [points at instrument] just broke last week and I am in the middle of a tour now. So, it is no time for me to think....' (Palacio Quentin, Appendix A.2)
> 'I also I can't handle it on my own the whole time. I mean it goes to slow.' (Uitti, Appendix A.3)
> Yeah, well it did shift, yeah, and it shifted mostly because I haven't had that much time to do to do much design' (Pluta, Appendix A.1)

In the next two chapters we will discuss use cases of the model. First we will discuss virtuosity and, in particular, the concept of 'Second Order Virtuosity' as introduced by the trio Brachiale (Hildebrand et al., 2016, pp. 163–181). In the following chapter we will evaluate the improvement of the Electrumpet in relation to the persona model. The model will be referred to further in the rest of the chapters of this PhD in relation to design decisions.

Chapter 4, the model in practice

In chapter 3 we defined a model that offers seven perspectives on instrument design. The author argues that the seven defined personas can help in the design and evaluation of new musical instruments. In this chapter we relate the model to virtuosity on new musical instruments.

4.1 Virtuosity and the model:

The persona perspective is intended as a means to evaluate and discuss new musical instruments on a number of subjects. In the way that 'The six thinking hats of de Bono' (De Bono, 2017) is a system for critical feedback in general, the 'persona model for musical instrument design' is a system specifically for the design of new musical instruments. There are similarities in use, however. Most importantly, when using a persona, the idea is to specifically adopt the perspective of that persona. Before adopting that position, it is, of course, important to reflect on what that position is and means. The position of performer is not a fixed position, but can differ from designer to designer. There is no absolute definition. The evaluation of an instrument through the model is still a personal evaluation, but should enable a wider critical perspective on its development, design values and biases.

In this chapter we look at the particular aspect of virtuosity in relation to musical instrument design, using the model. In this case we use the model to get a better grasp on the issue. Virtuosity is chosen because it is closely related to the expressiveness of new musical instruments (Dobrian & Kop, 2006, pp. 277–282). The ability to use virtuosity on an instrument is also one of the criteria that Sarah-Indriyati Hardjowirogo mentions when she tries to define a musical instrument, or rather instrumentality, as opposed to other sound sources. 'The idea of developing specific instrumental techniques over time is also congruent with the idea expressed by Auslander that, at least in professional instrumental performance, playing an instrument should appear more difficult than pressing a play button'. (Hardjowirogo, 2016, p. 18)

In relation to hyper instruments (Machover, 1992) virtuosity is particularly interesting from the idea of transfer of virtuosity from the original instrument to the hyper variant, as is the merging of acoustic and digital virtuosity.

Regarding the Electrumpet itself, the handling of virtuosity in relation to playing in different contexts (as discussed in chapter 2) has been difficult to bring into balance. The persona approach helped to define embellished requirements and strategies for design, composition, improvisation and practicing in relation to virtuosity on the instrument.

4.2 Different definitions of virtuosity.

Virtuosity is a word that must be used with care. Virtuosity is used differently depending on who you ask. It originates as a word defining high skill in something and has later gained its typical musical context (Hildebrand et al., 2016, p. 346). Rather than seeking an exact definition, all perspectives on virtuosity that could possibly be of relevance to musical instrument design are of

interest. The personas and definitions by the Trio Brachiale and Sam Pluta can help in this broader definition.

The Oxford definition of virtuosity reads: 'Great skill in music or another artistic pursuit'. This leaves quite a bit of wiggle room. In an instrumental environment, virtuosity mostly means the technique of playing and the complete control over an instrument, both in speed and finesse.

Virtuosity in an instrumental environment is also associated with the terms 'flow' and 'embodiment', as defined in ecological psychology (Gibson, 1979). The instrument becomes an extension of the body and the instrumentalist playing the instrument 'forgets' that it is actually an instrument, rather than another appendage of the body. Embodiment is extremely important to gain high speed, especially in complicated tasks. An instrumentalist or performer in a 'flow' state is so connected to the music that the awareness of the outside world dims and the player becomes one with the task (Csikszentmihalyi, 2014, Chapters 15–16).

From a neurological perspective there is no difference between doing tasks quickly or doing tasks in a refined way. They both require 'effort' when performed for the first time, and practice will reduce effort and increase the virtuosity level. When placed in the context of (digital) instrument design, it is wise to separate the two since they have different design consequences.

We want to note that a successful (musical) performer does not necessarily completely overlap with the virtuoso instrumentalist. The successful performer can lack the skills of the virtuoso instrumentalist but be very skilled in the timing of actions in order to captivate the audience. And neither does instrumental virtuosity guarantee a successful performance.

The Trio Brachiale acknowledges a shift of virtuosity due to the advance of electronic music and defines second order virtuosity as follows:

> 'A Second Order Virtuoso is an artist of exceptional skills with regard to technical and mental ability to create, observe, and shape time-based art works. This entails dealing with a wide range of processes, from simple interfaces to the idiosyncratic entities that become possible in environments integrating physical objects, electronic circuits and computers equally. She is well-prepared to make meaningful decisions, both intuitive and well-considered, across time scales from preparing years ahead of time to composing in real time.' (Hildebrand et al., 2016, p. 348)

Remarks from interview participants point in the same direction, and even more than with traditional instruments the gap between practising at home and performing on stage can be an issue. Sam Pluta stated*:* 'a musician with technical difficulties on stage did not practice enough' (Appendix A.1), and this remark is even more interesting in our context, since the practice routine he was referring to was setting up and breaking down his/her setup. So Pluta associates aspects of instrument treatment with control over that instrument and learning it. This is not completely unique to digital instrument design. Consider, for example, the preparation of reeds for the oboe, which is part of the oboe player's skill, or the

tuning of a guitar or a harp, which gets subtler and faster with years of critical practice.

Another particular aspect of virtuosity that relates more specifically (but not solely) to digital instruments is 'immediacy'. Joel Ryan already mentioned the issue of 'immediacy' and 'real time' in 1991, when referring to instruments made at STEIM for specific musicians (Ryan, 1991), and also defines this particular issue as problematic in relation to computers. The last sentence in Trio Brachiale's definition of secondary virtuosity gives room for incorporation of this type of virtuosity, but it deserves extra attention. The issue of immediacy can be treated technically (e.g. latency, connectivity), but in instruments involving complex processing and choice it is also a mental issue. Sam Pluta has designed his instrument with the possibilities of choice optimised for 'laptop musicians' (Pluta, 2012). He describes a method in which he operates the 'multidimensional space' he uses for improvisation. Which interface is used can also be of influence on immediacy. Using a leap motion controller instead of a mouse can improve 'gestural intuiveness and immediacy' according to Tormoen (Tormoen, Thalmann, & Mazzola, 2014).

The next section provides a 'per persona' breakdown of learning 'Second Order Virtuosity' in relation to new musical instrument design.

4.3 Developing Second Order Virtuosity:

Second Order Virtuosity states that virtuosity in the current era encompasses a much broader palette of skills. In this chapter we relate the possible development of those skills to the personas of our model. Rather than discussing all the skills, we will focus on the essence of the aforementioned definition of Second Order Virtuosity: 'to create, observe, and shape time-based art works'. Skills that are not time-based are important too, but will not be discussed.

4.3.1 Developing Second Order Virtuosity from an Instrumentalist perspective:

The instrumentalist persona will focus on the ability to implement 'technical skill' on the instrument. Dexterity is an issue, but so are embodiment and flow. It deals with the direct physical relation between the instrument and the instrumentalist. According to Fels (Fels, 2000), a 'highly intimate relationship' with the instrument is needed for 'high skilled performance'.

For an instrumentalist playing a new musical instrument, the first hurdle is to define 'high skilled performance'. Traditionally, instrumentalists can judge their virtuosity in relation to others playing the same instrument in a similar genre, aesthetic canon and culture, and judge that virtuosity in relation to a history of repertoire specifically written for the instrument or in a defined improvisation context (e.g. Bebop/hardbop, Carnatic music).

When there is no repertoire history in relation to the instrument, it also becomes harder to see the relevance of this type of virtuosity, as illustrated by this comment from turntablist Arjen de Vreede (de Vreede, Appendix A.10)

> 'There are many guys that are on all these DJ battles that outscratch me many times but they were spending days and days and days getting

> virtuosity on something which I find quite limited because well there is not much variation in scratch solo's… There was a little period where there was development but that has stopped'

There are competitions in which Scratchers show off their skills with little reference to music; De Vreede says:

> '...To go to all these beat juggling championships which for me are sometimes things like they even would lift a leg and then put their arm under their knee and scratch on and turn around. It became like DJ aerobics.'

In this case and in the vision of de Vreede virtuosity has become a goal in itself and the musical and artistic outcome has hardly any relationship to it. Playing a musical instrument has become the Olympics of performance and has little to do with the subtle dynamic interaction with others.

The PhD research focuses on 'instrumentalists designing their own musical instruments'. Mostly this means that we are talking about idiosyncratic endeavours. The repertoire developed is bound not only to the instrument, but also to the player. In learning traditional instruments, there is educational methodology; specific repertoire with increasing difficulty, often in the form of etudes, exists to pave the way for an aspiring virtuoso musician. None of the interview participants mentioned that they were using existing specific repertoire for learning their new instruments. For them, practising the instrument is limited to learning the repertoire for the next performance. That repertoire can even be totally improvised and a defined context for practice is then even harder to find.

4.3.2 Developing Second Order Virtuosity from a Performer perspective:

Tim Exile (Exile, Appendix A.6) most clearly stated this form of virtuosity from a performer's perspective:

> 'Which is a sort of combination of instrument technique and…Oh it is not actually technique it's more to this like knowledge. You have to kind of absorb your instrument and that isn't necessarily…That is not necessarily about practising really hard for six hours a day for a year or however you want to practise. It is it its…Well its basically its about you need time in front of an audience.'

Musicians on stage or in the studio whilst recording have a different mindset to musicians practising at home or in the rehearsal room. Going on stage with a newly designed instrument has additional difficulties that have to be dealt with. When experienced musicians perform extra tasks, their expressiveness suffers (Çorlu, Muller, Desmet, & Leman, 2015, p. 495). Instruments and the whole setup of the concert should be organised in such a way that the cognitive load of handling the concert and the new instrument is minimised.

Still, the concert situation is different no matter how small the extra task is. Sarah Reid (Reid, Appendix A.8) is making a trumpet addition called the Migsi (Reid, Gaston, Honigman, & Kapur, 2016) and she has a clear design goal for her

instrument that takes the overload aspect into account: '…not feel so overloaded with all of these extra tasks that they're spending more time figuring out how to use the instrument then they are just playing music.' She strives for a situation in which instrumentalists can immediately be in flow state and learning is limited. However, she relates how even she got into a performance situation where she 'forgot' that her third trumpet valve was actually the 'panic button' and ended up turning her electronics on and off while not understanding what was happening.

In the experiment of Çorlu mentioned above, he worked with a group of experienced players who were not experienced in doing extra tasks. Arjen de Vreede (de Vreede, appendix A.10) sees a tendency in himself to be more and more confident on stage with instruments that are not fully designed or 100% trustworthy and sometimes he even hacks as live performance:

> 'We discussed virtuosity and the number of hours that you need to be behind an instrument. If it comes to scratching and scratching clean its… I have never achieved those hours but if it comes to doing these crazy things, the unorthodox ways of using the turntable. That part has been growing a lot.'

De Vreede's experience suggests that it is possible to gain virtuosity in doing extra and/or multiple tasks and that it depends more on the personal relation with performance that the performer has.

Besides cognitive overload, stress can also hamper a performance. An inhibitor of confidence is an instrument or instrument setup that cannot be completely trusted or is so complex that a fault in setting it up is easily made. Stages can be much darker, more crammed, noisier and otherwise less ideal than the home situation. Concert organisers may expect electroacoustic instruments to be set up just as quickly as their acoustic counterparts, whereas they are much closer to instruments that are traditionally complex to set up, like drums or orchestral percussion, which are often set up by assistants or stagehands. These less then ideal setup circumstances can create stress, resulting in mistakes or an inability to reach the same state of flow as in the home situation. Sam Pluta (Pluta, appendix A.1) puts it as follows

> '…yeah I do practice. I think the practice with an electronic instrument is very different, then an acoustic instrument because most of it is actually turning the thing on. I think that you know if you see people go into a performance and their software doesn't work, to me that is just like; they haven't turned it off and on enough. Because when you turn off and on then you find the things that go wrong. You discover the things that are not triggering correctly to like start the patch. And just basic little things, like the instrument is so finicky. It's the only instrument that the keys just basically fall off in the middle of the piece. You know, that is like part of it. It is as if you had a flute that like every time you took it out of the bag it could be in shambles. No one would play that instrument but an electronic instrument is like that…'

This extra overhead does not just apply to the instrument itself. In electroacoustic music, the whole concert might well be complex in nature and

demand a dedicated approach as well. Anne la Berge (la Berge, Appendix A.7) heeds the advice Joel Chadabe gave her in this respect:

> …When I had Lisa and the micro modular and some MAX and I was having to plug and play for concerts playing other people's supercollider pieces…I was in New York and Joel Chadabe, he looked at what I was doing he said: "You need to streamline". because I could do it all but it was just a lot of handling also between pieces eh and I took that really I said I thought: "of course I do". And that was one eh piece of you know one sentence that I will always remember…'

Streamlining has become an important aspect of her setup. She also takes care of the aspect of streamlining for other people playing her pieces, which mimics Reid's effort to minimise overload during performance.

Although streamlining and patch organisation are aspects of *Second Order Virtuosity*, they concern mainly preparation and organisation, rather than training. Sam Pluta (Appendix A.1) gives one mandatory method of practising: 'Taking the instrument apart and assemble again, it will make you aware of weak points in your setup and setup organisation and prepares you for setting up on stage'.

Second Order Virtuosity in relation to the performer persona in our model is the ability to deal with the use of new technology on stage. It is about the ability to fix technical problems while on stage, but also about the mental ability to stay calm in uncertain and even broken situations. It is about the ability to plan a performance, including all the technical details, and minimise technical risk and technical distraction through preparation and streamlining. Most importantly, of course, it is about the ability to converse with the audience and other virtuoso performers sharing the stage, despite the extra attention inevitably demanded by technical details. It is also about the ability to converse with the audience through the machines.

4.3.3 Developing Second Order Virtuosity from a Luthier perspective:

Many of the skills involved in making instruments are not time-based, which is the prerequisite for *Second Order Virtuosity*. They are the physical making of the instrument, the electronic skills and the programming skills, etcetera. Sound though is inherently time-based.

Virtuosity from a Luthier perspective involving digital sound means a high level of sound synthesis skills, sound-processing skills on acoustic input or sound skills associated with analogue synthesis. Sound virtuosi train their ears to be susceptible to minute differences in sound and can transfer their audio analysis in adjustments to the synthesis. With regard to this persona, the difference in skill level indicated by the interview participants was very big and ranged from using samples and loop-based playing to very intricate sound design. The minimum skill level needed is connected to the context in which the sound is used. Tim Exile (Appendix A.6), who is active in the electronic dance scene, showed that the disembodied treatment of sound could still lead to a skill competition when he was asked if he compared himself to others:

> '...There was this kind of space race. For ways of, you know for new sounds and new techniques and so on. So it was more that it was more like the processing side of it just like what is the potential? What can you potentially do with electronic sound? It was totally sound based it was that disembodied sound that I was interested in... I compared closely to the warp records people Aphex Twin, Squarepusher, Plaid, Clark. All those guys, basically the warp records roster and reflex records that whole IDM well brain dance whatever you going to call it. So I think; yeah there was sort of a competitive element, or this kind of like I can make an even crazier sound then you can make kind of approach. Or like a sequence of in crazy ways or I can make crazy transitions and so on. Now actually looking back on it I realise it was more about transitions then it was about the actual sounds…'

Just as instrumental virtuosity is no necessity for, or guarantee of a good performance, neither is 'Luthier virtuosity' mandatory. There is a caveat, however:

No interview participant talked about the control over the quality of the amplified sound during the performance, which should be extremely important to any musical performer on a stage. An acoustic performer will associate the quality of the amplified sound on stage as the task of an engineer and/or producer: placing a sound in space, determining the amount of reverb, EQ and balance, etcetera. In acousmatic composition, though, these skills have traditionally been part of the trade (Emmerson, 2007), (Harrison, 1998). Whether this is, or should be part of the trade of an electro-acoustic instrument designer has not been clearly defined and depends on the instrument, but it is telling that the topic did not come up in the interviews that were conducted. We would argue that the topic deserves much more attention in NIME-related literature and also shows where a persona-based analysis of musical instruments uncovers topics that have to be addressed. (Pierre Alexandre Tremblay & McLaughlin, 2009), (P.A. Tremblay, 2017).

The quality of the amplified sound during performance is not only an issue at the end of the audio chain, but should also be tackled in the instrument itself. The mapping of controller/sensor values to address level and EQ control on individual audio strands can be automated within the instrument.

Second Order Virtuosity in relation to the luthier persona is about synthesis and sound processing skills. The implementation of these skills is an added value to an instrument and are a defining skill in some contexts. Skills that always need attention in relation to new instruments are skills traditionally attributed to the sound engineer.

4.3.4 Developing Second Order Virtuosity from an Improviser perspective:

In his classic work on improvisation, Bailey acknowledges a lot of styles but also defines two forms of improvisation: 'idiomatic' and 'non-idiomatic' (Bailey, 1992). The latter is mostly found in so-called 'free improvisation' although the

notion got challenged recently. 'When Bailey (1992) coined his classical term of non-idiomatic, there still existed a need to distinguish between traditional styles and genres and the way they were made relative in the new improvised music context. In later developments, this relativity of styles and genres have become increasingly a matter of course' (BERGSTROEM-NIELSEN, 2016). Musicians do not stick to one idiom while playing and everything is up for improvisation.

Except for Sebastien Schiesser (Schiesser, Appendix A.9), all the interview participants were familiar or very familiar with improvisation, using it in relation to their instruments and in their professional practice. There are differences in their approach, however, and those differences have implications for the instrument design.

Tim Exile (Appendix A.6) performs as a solo performer in a dance-related context. His improvisations are probably the most idiomatic of the interview participants and are beat-based, using loops. He designs his own instruments in relation to Native Instruments from a performer perspective and states: 'Well, basically I want there to be instruments that are entirely focused on performance and improvisation'.

All other participants improvise in a free context or a context determined by an original composition. Sam Pluta (Appendix A.1) explicitly designed his instrument to be operable in the context of free improvisation with other musicians: 'virtuosic instrumentalists can access anything that they wanted to do instantaneously and so I basically wanted to set up a system where I can access anything that I wanted to do instantaneously, so that's kinda how I got into it'

The aspect of immediacy has two components. It is an instrumentalist feature, but it is also an improviser feature when it means immediate, total (unexpected) change, which is a vital skill in free improvisation without premade agreements.

In both Pluta's and Exile's example, it is clear that an instrument has to be designed to be suitable for improvisation. Whereas in the early days of free improvisation it might have been mandatory not to use any material that could be seen as preconceived, which Uitti calls 'the improvisation dogma', nowadays free improvisation 'allows' for paraphrasing as well, and in this context patched electronics are the digital equivalent of preconceived phrases.

The context in which the improvisation takes place is important in the design of the instrument. What can be an asset in the case of Exile: 'improved accessibility of loops', for example, can be a disadvantage for Pluta's context: 'and then the sound is going into a process down here which locks the sound right? Like there's something what's like loops or buffers or something'

While designing for improvisation was an issue in the interviews, the development of improvisation skill in relation to the new instrument was not. The idea of developing an etude system for new instruments (chapter 7) from the perspective of improvisation skill was brought up by the author and approved, but the participants did not spontaneously bring up improvisation skill development in relation to the instrument.

The design of instruments with the specific purpose of being very useful for improvisation would suggest that there is some way to evaluate the success of the attempt. However, the illusive character of art in general (what is good art?) and improvisation in particular (can and should we define it?) will make such an evaluation attempt very personal. Rodrigo Constanzo gives a good example of a personal approach to a more structured improvisation practice in his PhD thesis, defining the concept of "Making decisions in time" (Constanzo, 2017)

> 'Making decisions in time (technically driven aesthetic developments) is a conceptual framework and analysis tool for improvisation which focuses on separating decisions into Material, Formal, Interface, and Interaction streams. In this way it is both an aid for thinking about improvisation in a general sense, as well as a manner in which to reflect on and improve one's own improvisational practice. The dedicated chapter on this framework covers the conception, background, development, and future plans for the system, including several in-depth analyses made with the system.'

Defining *Second Order Virtuosity* from an improviser perspective is very dependent on the improvisation context. The improvisation context determines the musical parameters that are up for treatment in the instrument system. If the improvisor persona's design values are well defined with regard to that context, it will allow for a clear dialogue with the other personas.

4.3.5 Developing Second Order Virtuosity on the Electrumpet from a Tinkerer perspective:

Like the improviser, the virtuoso tinkerer persona is also very context dependent. Typical tinkering activities include live coding, live patching, circuit bending and patching analogue synths, etcetera. Virtuosity is then about the speed and the control with which a person is able to perform those activities from the perspective of having new, inspired, divergent, playful ideas. Live coding is an example of a virtuoso activity with a tinkerer component done in a skill competition, but in contrast to the turntablist Olympics described in the instrumental persona section, this is about musical innovativeness.

Arjen de Vreede (de Vreede, Appendix A.10), originally a turntablist, associates strongly with the tinkerer persona in a more open fashion then the activities mentioned in the last paragraph. He has also incorporated it with his performance persona:

> 'At one time I was in Canada playing with Jacques Palinckx and I had a turntable that was so old it became microphonic so anywhere, everywhere I would touch it would give a different sound and some of them would have low end other high end so I was drumming all over this turntable and it just needed a little effect and it was like a complete new instrument and there was not a record on the turntable. And that that concept I have been trying to work out and this really went far like, there have been gigs, one time in Brno in Czech Republic … and then I went to the second hand. The gypsy second hand shop because I went to Brno quite often and knew the gypsy second hand shop. … so I went to that

> shop and I bought a turntable like a little suitcase turntable that is transportable that you had in the 60s and 70s plastic build and I would just go on stage with it and then I take a screwdriver with me and I'd sit at the front of the stage and the first two songs when they were improvising I am just unscrewing taking all the screws out of the thing and then the speaker out of the lid and then I put the speaker on the turntable and I take the needle and I put the needle in the speaker which is direct feedback, and then eh the speaker starts to scream and if you move the needle towards the centre of the of the speaker towards the cone you get really screamy high note Jimmy Hendrickx like feedback. If you go to the outside of the speaker it will be a lower ... (makes a popping sound); like a diesel engine almost. So, there is no turn... no records involved anymore and I've done many shows that are with turntables without any vinyl's.'

Tinkering is not restricted to the examples given above. It can be part of any electroacoustic instrument and instrument design process. It can be an artistic choice to have an electroacoustic instrument that is never 'finished'. Just like designing the suitability of an instrument for improvisation, it is also possible to design the suitability of an instrument for tinkering. An example of design for tinkering is the design of live coding environments.

In order to tinker, the instrument designer has to create a situation in which the instrument can be picked up, played briefly, changed, played briefly and so on. A pick up and play situation has to be created. As also noticed by several interview participants, having the instrument that you play close at hand will create a different dynamic towards development and practice. Most acoustic instruments are easy to unpack and ready to play. Creating a similar situation for the electronic instrument is a must and even more so for hyper instruments where the electronics intrude on the originally purely acoustic situation, and it needs extra motivation to be incorporated in practice and tinkering sessions.

As with *Second Order Virtuosity* from an improviser perspective, *Second Order Virtuosity* from a tinkerer perspective is very dependent on the musical context. And it is even more dependent on the instrument itself. Tinkering skills can vary greatly but may include soldering, coding, patching and prototyping. Instruments can be designed in such a way that they lend themselves better to tinkering.

4.4 Virtuosity in relation to the composer and designer personas:

Composition and design are not time-based activities as meant in the definition of *Second Order Virtuosity*. When discussing these personas in relation to virtuosity, we do not try to look for the virtuosity aspects of these personas, but look at how the composition and design personas can implement virtuosity aspects brought forward by other personas and their relation to virtuosity in general. They can implement that as a challenge to the virtuosity of one of the other personas.

4.4.1 Developing *Second Order Virtuosity* from a composer perspective:

Traditionally, composers have sought out virtuoso performers to perform new work, just as virtuoso performers have commissioned composers to write for

them. Sometimes virtuoso performer and composer were one and the same, as in the legendary and archetypical example of the virtuoso violinist Niccolo Paganini (1782 – 1840).

New instruments are a challenge for composers on two fronts. Firstly, they do not necessarily allow for the notation system traditionally used by composers, as the sounds they produce cannot be written as dots on a staff. Secondly, the instrument can contain part of the composition itself. One instrumental action can result in the activation of an algorithmic process that defines the organisation of a string of musical events in time. After the instrumental action has been performed, an algorithmic process in the computer takes care of its execution. In that case, part of building the instrument's system is algorithmic composition, which is defined as 'the process of using some formal process to make music with minimal human intervention' (Alpern, 1995, p. 1). This is a form of 'micro algorithmic composition' and for the Electrumpet this process is defined as 'composing from the instrument'.

The algorithmic aspects of the instrument and the interaction with these algorithms have to be brought into accordance with each other in such a way that instrumental skill and these 'micro algorithms' are merged in a meaningful and expressive manner. This means that the composer should not only be concerned with the resulting sound, but also with the quality of the interaction and its potential added value for the composition. Chapter 7 clarifies the implementation on the Electrumpet.

When the composer becomes responsible for algorithmic content on the instrument that determines how the instrument sounds, it means that the composer in part also determines that instrument's identity. The personal voice of the instrumentalist persona now merges with the personal voice of the composer. Uitti states that 'three notes of an improviser are enough to know the improviser'. (Uitti, Appendix A.3). The same is true about the first three bars of most canonical composers. The last addition then becomes: "Ah, that instrument is composed by...".

4.4.2 Developing *Second Order Virtuosity* from a designer perspective:

The designer persona is important in relation to virtuosity as the 'middle man'. Depending on the context and the preferences with regard to the other personas, the designer persona has to put together all of the (virtuosity) requirements from the other personas in order to create an instrument system that will allow these requirements to be fulfilled. Besides that, the designer persona also has to look beyond the direct world of instrument design to seek knowledge that can be helpful to fulfil those requirements. This knowledge has to range from cognitive psychology and neurology to knowledge about state-of-the-art electronics, sensors and materials and other relevant fields, depending on the artistic needs of the other personas.

Sam Pluta gives a good example of the use of information theory as the foundation for instrument design in the context of virtuoso laptop performance. He states that a virtuoso performer strives for a 'great deal of information and thus the possibility for complexity' (Pluta, 2012, p. 6).. He then explains how he

can reach complexity from patching together a lot of simple building blocks (the complexity is defined by the connections, rather than the building blocks themselves) and his instrument now has a grey-scale range from simple to complex.

The design cycle does not have to be purely from the music field outwards. Even performing instrument designers can be equally influenced and inspired by 'outside fields' before starting to build their instrument. A merge of personas and experiences that are both outside and inside our model can result in very personal and unique instruments. Rajesh Mehta explains how his instrumental concepts were the result of the merge of his acoustic engineering background and his musical background:

> '… was directly the science of sound. The work in the acoustics engineering consulting company and then the lab that I was in and then just pure experimentation and in that way, I would say probably the experimentation environment of Mills also helped… It was more from my direct relationship to acoustics I think and then the environment of Mills and making the decision to go into professional music and studying composition with Braxton that I just started experimenting with the trumpet taking slides out and looking analysing how the flow… and connecting instruments with different tubes happened later in Amsterdam. So all this, and also making what I did in the acoustics lab was connected to making mutes. So I was also busy trying to make kind of my own mutes also different sound reduction devices, acoustic ones; and then there were a series of concerts I think I saw Ben Neil once with his mutantrumpet, yeah that was 89. 1989 in San Francisco and the idea of having a tube to displace the sound impressed me…'

Thus Mehta's acoustic skills (Luthier persona), his creative improvisational skills (Improviser persona) and his existing trumpet virtuosity (Instrumentalist persona) have been merged together and transformed (Designer persona) to create a new instrument (consisting of tubed together parts) (Mehta, 2012), (Mehta, 2013)

4.5 The development of personal voice:

An aspect that is very closely related to virtuosity is the development of musical voice. While this has traditionally had strong connections with instrumental virtuosity, in our model it has connections with all the personas. It was often brought up in the interviews and, with the exception of Sebastien Schiesser (Schiesser, Appendix A.9), the development of musical voice has been the driving force behind all the instrument development efforts by the interview participants. Arjen de Vreede (de Vreede, Appendix A.10) was already mentioned in relation to instrumental virtuosity on turntables. He shifted his attention from skill development to content development after becoming fed up with the use of virtuosity in the context of his musical instrument:

> '…I decided not to be part of that and I thought my power is more anyway in the arrangements; like I work with bands and I put in things that have harmonically an effect on the total and on the song and in idea and conceptual effects on the music of the people that I was collaborating with at the time….'

The importance of personal voice was a key talking point in the interview with Frances-Marie Uitti and she emphasised the term most clearly (Uitti, Appendix A.3)

'…I really wanted to do more solo work, small chamber music where the voice was not covered in other words' (Frances does this statement after discussing orchestral work she did previously), '...it is always been and then it became later evident what this was. It was a search for a voice. What is my voice other than just playing the cello and having the cello's voice beyond a traditional repertoire, which has a codified way of playing?'

This is an interesting remark by Uitti. Orchestral work requires you to play in a certain way, which requires a certain kind of skill; a skill that is allowing composers to use each colour of the orchestra. This allows composers to write for symphony orchestra without knowing which symphony orchestra yet. At the same time this limits the freedom for the individual performer to shape his or her own voice. In search of her (cello) voice, Uitti started improvising (considered a sin at the time in traditional classical music) and developed a name as a performer of new often commissioned music repertoire. (Uitti, 2018), (Uitti, Appendix A.3)

The invention and further development of an idiosyncratic instrument follows a similar path to the development of a personal voice through commissioned work in the case of Uitti. This is illustrated by her own ventures into the development of the double bow (UITTI, 2000) and the augmented cello (Freed, Wessel, Zbyszynski, & Uitti, 2006), and her newest project, which is an actuated instrument bowing on spinning rods. Uitti was revolutionary when she started changing her instrument as a performer, but nowadays there are more instrumentalists who see the development of an instrument as part of their search for a (unique) voice. That unique voice is not limited to the embodied relation of instrument and instrumentalist and it can be completely disembodied, according to Tim Exile, which is something we already discussed in relation to the Luthier persona.

Sarah-Indriyati Hardjowirogo devised a set of criteria for instrumentality, 'criteria that matter for the construction of an instrument's identity' (Hardjowirogo, 2016, p. 10). Hardjowirogo seems concerned with the identity of the instrument itself while Uitti refers to the affordance the instrument gives to the player to create their own voice using the instrument.

4.6 Chapter conclusion:

In this chapter we looked at virtuosity in relation to the design of musical instruments. We used the broader concept of *Second Order Virtuosity* in doing so. Using this approach allowed us to unearth some underdeveloped and/or specific

aspects of virtuosity in relation to the development of new musical instruments and use a systematic approach for discussion that allows for the issue to be worked on from different perspectives.

The instrumental persona is traditionally connected to virtuosity. In this chapter we saw that the professional performers that were interviewed approach virtuosity and skill development from a variety of perspectives depending on the context in which they operate, their artistic choices and past experiences.

Composing and designing for virtuosity has always been part of the musical discourse. The advance of new technologies has opened up new possibilities that merge composition and instrument design. The integration of design methodology into musical instrument design unlocks useable knowledge from other scientific fields to design for virtuosity.

The ability to develop a personal voice on an instrument is traditionally connected to instrumental virtuosity. In this chapter we argued that the development of personal voice is connected to all the personas of the model when dealing with idiosyncratic new (electroacoustic) instrument design.

Chapter 5: Model versus Practice, the model applied to the Electrumpet

In this chapter we discuss and evaluate the Electrumpet's design improvements during the PhD period; we discuss especially how improvement was driven by the persona model. This chapter has a lot of details that might especially be interesting for other hyper instrument builders but might be a little overwhelming for others. The chapter is deliberately subdivided in a lot of short titled sections so it can be used as a reference for people seeking examples that can benefit their own practice. The evaluation sections give meta opinions on the improvements that were implemented.

This chapter describes the practice in relation to design and how the tension between the two forced major changes. It is inherently personal and it provides a snapshot of the 'Electrumpet state of things' at the end of the intense self-reflective period that was the PhD. The interviews and subsequent analyses have sharpened the awareness for important aspects of instrument design.

This chapter does not provide all the requirements ever implemented on the Electrumpet. Requirements that made total sense when the instrument was just designed might now be so trivial that they are not even thought of anymore. Information and advice pertaining to instrument design that was shared by the interview participants is mentioned when it influenced particular design improvements especially when the improvement was major. The influence of the interviews has been huge but mainly indirect. The interview participants have driven the development of the persona model and the persona model drove the redesign.

This chapter lays out as good as possible the argument of design decisions in relation to the persona model. This has been on purpose. The model is intended to be used in a personal manner. The design decisions connected to a particular persona in the model are informed by a subjective list of requirements that only the designer of the Electrumpet attributes to that specific persona. Even more narrowly, the requirements are the result of analysing an instrument with the skill set, knowledge and experience sublimated in the value set of a specific persona at that moment in time. The model is intended as a subjective qualitative tool for evaluation.

There could be an incentive to try to describe all the possible values that a persona could possibly have and see those as an absolute measure that can be scored in a Rubric fashion. That would mean taking a good vs bad position in instrument design. Such a position might seem valid when those values are concrete and practical in nature but even then, there will be exceptions. A requirement for sturdiness is obviously moot for purposefully fragile instruments that are supposed to break during performance (Haddad, Xiao, Machover, & Paradiso, 2017) or instruments that are purposefully repurposed during performance (Appendix A.10). In the first case the designer persona is very engaged and in the latter the performance persona; both though with very different positions then the designer and performer personas in the Electrumpet case.

The function of the model is not to dictate a certain position for any of the personas. The purpose of the model is that it requires the designer to take a position for each of the personas even if that position is to forgo the influence of said persona. Analysis of the design through the model might also be an incentive to put in specific efforts or to contemplate activating other people with specialities that centre around these personas.

Even the requirements for instruments that follow a more traditional use scenario will vary substantially depending on the values that are attributed to different aspects of the design. It is in defining, analysing, using these values for design, appraising the results and defining future goals that the persona model offers its value. As an advanced use case the Electrumpet is subjugated to the model. Each persona's influence on its redesign will be discussed in separate paragraphs. Each of these paragraphs will start with an analysis of the state of the instrument at the start of the PhD, it will then describe its development within that persona and there will be an evaluation of the functioning of the persona to conclude.

In this chapter, the term persona always relates to the position of the designer of the Electrumpet unless explicitly stated otherwise.

5.1 Electrumpet design from the instrumentalist persona perspective

Bias, experience and expertise are all terms that related to the instrumentalist persona at the start of the PhD period. As was discussed earlier in relation to participatory design (Iversen et al., 2013) design is a negotiation of different values. In participatory design it is the negotiation of the values of different participants and in the design of musical instrument that changes to the negotiation of values of different personas.

Expertise has its advantage in this negotiation as it is possible to refer to past best practices but it can also hinder an objective analysis because of a bias that is developed together with that expertise. Values are not always clear. They may be so obvious to us that we are not aware of them. A research on the use of values within interaction design research for children states it as follows: "One of the main takeaways of this paper is that there are diverse ranges of values that drive our work. Many of these values go unnoticed (perhaps even unspoken, at times) because we share them. The values that are explicitly spoken in the work may be different from the core values held by the investigators." (Yarosh, Radu, Hunter, & Rosenbaum, 2011, p. 143).

The bias in the instrumentalist persona constituted the opinion that instrumental knowledge and experience was underrepresented in existing NIME literature and the scientific community somewhat naïve. This was an opinion shared by some of the interview participants when familiar with the NIME community but also in passing discussions. Electronic musicians do not always share the musical background and training that musicians in other styles need to be successful. The musicians background can be in a completely different field of experience as a Japanese study on experimental laptop musicians showed (Loubet, 2000, p. 1). Expertise and experience related to the Electrumpet comes from forty years of experience as a trumpet and flugelhorn player in different

musical settings, a conservatory education and 20 years of professional artistic practice.

The acoustic musical background focussed the design effort as related to the instrumentalist persona towards a direct translation of the instrumental 'feel' familiar from the acoustic experience. This led to certain prejudices and hang-ups in the design propositions, that were mostly subconsciously present while thinking of improvements thus hindering alternative possibilities. A few prominent examples:

- The valves are to be used as they are on the trumpet. That means some form of direct match between the sound pitch and the valves. With four valves it is possible to reach one octave.
- Halve valve play as is used in Jazz and new music could be implemented on the digital valves.
- Expression is sought in the direct relation between the continuous sensors and sound. Digital sensors on the other hand are very suitable to make choices in presets and such.
- Digital sensors are subservient to continuous sensors which are really the expressive sensors.

The first of these propositions was hard to match with one of the design principles; the Electrumpet was not supposed to be a synthesizer but would always work with the input of acoustic trumpet sound. The halve valve idea could also be implemented on the infrared sensor playing it with the left hand. It was deemed better since it would allow the other hand to use the acoustic valves at the same time. The third and fourth propositions were very much informed by the instrumentalist background.

The Electrumpet is a hyper instrument, it combines acoustic and digital interaction. A new definition was introduced called 'True hybrid play'. It meant a form of 'joint embodiment' where the player is not consciously aware of playing the acoustic instrument versus the digital augmentation. Or to put it differently that there would not be a different level of flow (Csikszentmihalyi, 2014, Chapters 15–16) for digital control vs acoustic control. Clearly the acoustical control far outmatched digital control. The acoustic trumpet was completely embodied, the digital trumpet wasn't.

A good insight in the technical and instrumental thinking of the Electrumpet before the PhD is given in the article written for the NIME conference in 2012. This was already an update of the original Electrumpet article (Leeuw, 2012) (Leeuw, 2009).

5.1.1 Improvements in the Electrumpet design related to the instrumentalist persona

Although 'True hybrid play' as defined in 5.1 was not sought after by any of the interview participants, few of them being hyper instrument players, most of them dealt with the issue of virtuosity in relation to designing electroacoustic instruments. While virtuosity is not the same as flow it was often treated as such

by the participants. Csikszentmihalyi describes flow as an inner state of the musician; virtuosity is a subjective description of a musician's 'great skill'.

Virtuosity in relation the Electrumpet got a different meaning from the interviews. There were two different approaches in describing the interaction with the instrument that related to the use of the instrument within pieces and improvisation. In the first approach a new instrument was designed for each new piece; a new instrument meaning the same set of sensors or the same controller(s) but with different sound processing and mapping strategies. The second approach focused used one instrument for all pieces with attention for the ability to change quickly between discreet states. In this text they will be called the 'per piece' and 'discreet states' approaches.

In the 'per piece' approach the same hardware instrument is used but the way in which the sensors on the instrument are mapped to sound processing changes per piece and is basically reinvented to fit the piece's requirements. The sound manipulation mostly focuses on continuous sensors that are mapped to relatively straight forward sound processing. Controlling these continuous sensors is its main means of expression apart from its possible acoustic input. It comes close to what an instrumentalist does when continuously manipulating his or her sound, phrasing and ornamenting.

In the 'discreet states' approach the instrument has multiple discreet states that can be moved between quickly. The ability to change quickly is its leading feature. In this case the system with which the changes are handled is its main means of expression. The change of sound becomes much more of a choice problem comparable to fast playing and sort of intuitively knowing which notes are to be played next.

The Electrumpet redesign was based on both approaches next to each other. This gave in essence two modes of instrumental operation: staying in a certain 'preset' state and manipulate that state with the continuous sensors or move quickly between 'discreet states'. Obviously these two modes of operation can be mixed. The analogy with acoustic instruments is either playing fast and/or paying a lot attention to details like ornaments, sound, playing style etcetera.

The 'discreet states' approach did not yet exist on the Electrumpet even while it did not strictly have a 'per piece' approach either. A new 'phrase system' implemented on the digital valves was invented. Although the sensors for these digital valves were already present on the instrument for their similar feel with the valves on the acoustic trumpet they had never been properly used, they were physically further augmented to make them quieter using felt inside and out in analogy with regular trumpet valves. Furthermore, these continuous sensors have now basically become digital in the way they are used as being either depressed or not.

The redesign started with a strict division between the 'per piece' and 'discreet states' but the strictness was abandoned in the iteration of the further design. Phrases are now also used within 'discreet states', especially short ones; some of the continuous sensor mapping is also mirrored in phrases that directly point to a continuous sensor position.

With the invention of the 'phrase system' 17 digital buttons that were no longer needed were subsequently removed making the physical Electrumpet layout much simpler.

Figure 5 Top: new Electrumpet top plate, Bottom: old Electrumpet top plate

The 'per piece' approach within the redesigned Electrumpet system relates to the implementation of continuous sensors and audio description for the control of sound and control parameters. From these the continuous sensors needed an improvement after the redesign to bring that part of the system up to par with the new possibilities of the phrase system. In the old situation the continuous sensors were often used in a discreet manner and if not lacked precision. The improvements are discussed in the next paragraphs. They were implemented at the end of the PhD period so there is little to no playing experience.

5.1.1.1 Ribbon controller and haptic feedback

A ribbon controller is used as a semi continuous controller. Its timing of discreet transitions is dependent on the feedback that is provided. In the new version of the Electrumpet haptic feedback was implemented to be able to feel the precise timing of transitions. These transitions were originally only discernible through visual and auditive feedback. Haptic feedback can improve the control over this sensor: "in expert performance it is the tactile and kinaesthetic which is the most important" (Marshall & Wanderley, 2006, p. 226). Haptic motors with a dedicated haptic motor control are used for this implementation (Texas Instruments, 2013).

To improve sliding over the ribbon controller a textile thumb sock was made.

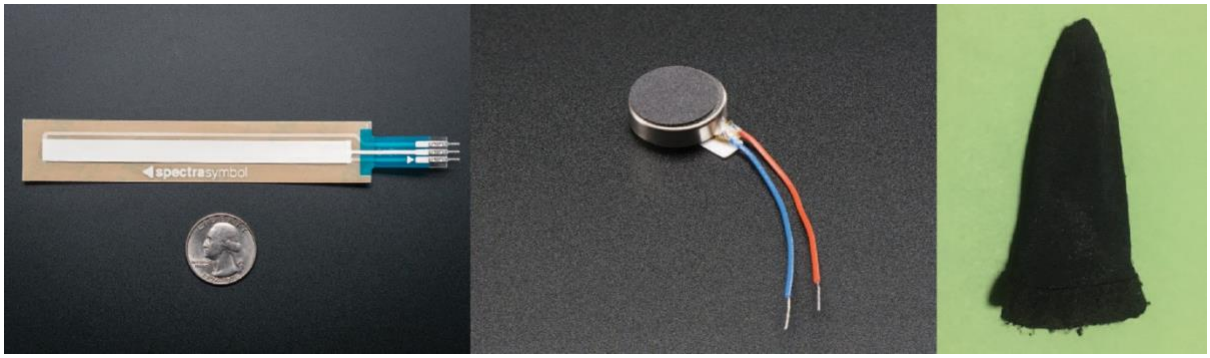


Figure 6 ribboncontroller, haptic motor and thumbsock

5.1.1.2 Pressure sensors to digital valves

Two pressure sensors were on the third valve of the Electrumpet in the original instrument. The index and middle finger of the left hand operated these sensors. These sensors were mostly used for a continuous form of transposition. In their extreme positions the sensors could be used for a transposition of one octave up or one and two octaves down mostly with some extra mapping to sound processing added. Glissandi in between these extremes were possible as well. There was little precise control though. Only the extreme positions could be held stable.

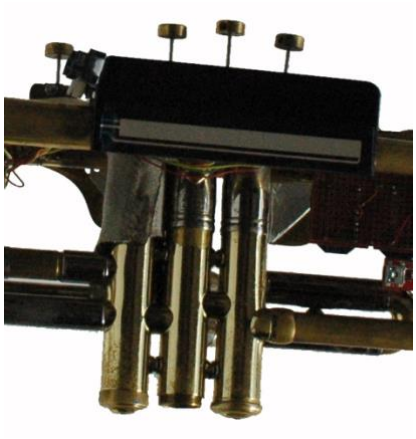


Figure 7 The fabric on the third valve contains two pressure sensors

The development of the interactive harmoniser took away the need to have the discreet extreme positions as they could be made into a code phrase. Using the pressure sensors for glissandi happened less and less since the focus was more on developing the harmoniser. There were also physical considerations: a ganglion cyst had developed on the index finger, possibly because of extreme force, so that disqualified the pressure sensors further. Since these sensors had proven their usefulness in the past they were replaced with ergonomically more healthy alternatives in the physical upgrade. The removal of the 17 digital buttons created room for the implementation.

The alternatives for the pressure sensors are two valves similar to the digital valves that were already present on the instrument (see 5.1.1). The placement of these valves was intricate and also involved extra support for the fingers to

create an optimal access. The optimal ergonomic implementation is still being worked on.

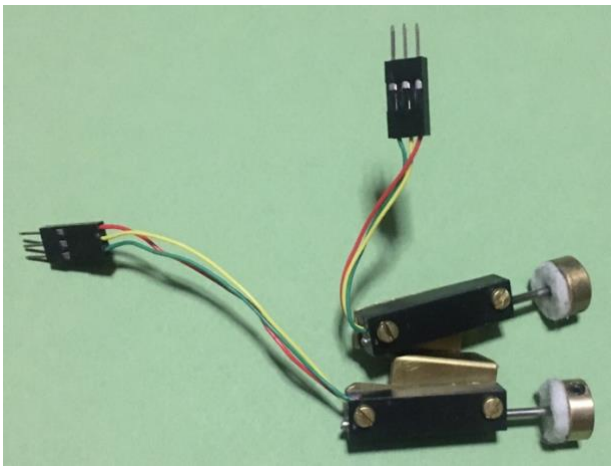


Figure 8 digital valves on a messing contraption, which is soldered on the 2nd and 3rd valves of the trumpet

5.1.1.3 Infrared sensor to Gestic sensor

An infrared sensor (Sharp, 1999) was used to measure the location of a hand placed in front of that sensor. The sensor was hard to use as the reflection of the Trumpet bell made the sensor less reliable. In performance situations, infrared stage lighting could disturb the sensor as well. To improve the infrared sensors reliability its range was limited in the software. The sensor was replaced by a much more sensitive and trustworthy 3D touch sensor (Microchip, 2012). Although not explored thoroughly this sensor has the potential for much more subtle sound manipulation then the 1D sensor.

Figure 9 left is the old infrared distance sensor from Sharp and right the new 3D touchpad from Microchip

5.1.1.4 Adding a gate microphone

The gate microphone was an addition anticipated before any other redesign happened. A suitable microphone was found in the piezobarrel (Francis, 2013). Because of certain resonances within the mouthpiece cavity it cannot be used as the main microphone. These resonances get more prominent through the effects of the Electrumpet. The piezobarrel is used as a gate microphone. This prevents not only sounds from other instruments but also echoes from Electrumpet delays to be unintentionally processed (again).

The gate microphone was mainly implemented for operation within an environment with more players but it can also protect the system from feedback. The gate microphone sound is used for sound analysis since it gets the purer trumpet sound. It sits also close to the mouthpiece and the sound it picks up is 3ms ahead compared to the sound in the other microphone thus reducing latency.

Figure 10 PiezoBarrel mounted on trumpet mouthpiece

5.1.1.5 fixed microphone to clip microphone

There is a difference in working with a fixed microphone compared to a microphone that is attached to the instrument. Originally, working with the microphone distance as an extra parameter was part of the expressive repertoire. For Anne la Berge (Appendix A.7) microphone technique is an important aspect of her instrumental repertoire in relation to live electronics and she has been inspirational in that aspect:

> 'The biggest aha was in the, as far as eh my my flute playing and the electronic music domain was using the microphone ……. just first using a microphone realising what that does and then starting to develop. Cause that's the first step in electronic music is how you interact with amplification. and eh using the full flute, the end of the flute, you know…What what does this tube do and what do I do as a tube ehm that this microphone and the amplification can eh expand... Or change the perception of my audience or change my perception of how I want to produce sound.'

Some new implementations were hindered by the varying distances of the fixed microphone though. Moreover, the fixed microphone position puts the player in a fixed position as well. This somewhat hinders expressiveness and in combination with hefting a heavier sensor augmented instrument there is a risk for back problems during longer concerts.

Before the invention of the harmoniser microphone technique was used within the Electrumpet. There were less opportunities that the instrumental persona wanted to explore at the time. Axel Dörner shows the power that acoustic sound manipulation combined with live electronics can have in his composition for Trumpet and Electronics. (Dörner, 2018)

5.1.1.6 9-axis sensor

Having freedom of movement through the clip microphone, means that trumpet movement can become a new parameter in the 'fixed instrument' category. A 9-axis sensor is implemented for that purpose (Bosch, 2014). Experimentation has been too short to draw any conclusions.

5.1.2 Learnability

In the previous paragraph's, improvement of the instrumental quality of the Electrumpet from the perspective of the physical interaction with it was central. An improved instrument through better sensory response and less latency was the goal.

An instrument thus improved also affords an improvement in its learnability which is another instrumental criterium (Hardjowirogo, 2016, p. 18). A gesture comprised of a number of steps will be hard to be internalised as a single gesture when each step has to be double checked for confirmation that the intended change was indeed made. The phrase system which is explained in more detail in chapter 6 totally eliminates that problem because there are no in-between steps. A phrase is either successful or not. Furthermore, unsuccessful phrases are rare since the most reliable sensors are used for the phrase system. In the rare case that a phrase is unsuccessful because of a hasty execution the system seldom interprets it as an alternative phrase with a different consequence.

Learning the instrument from the perspective of 'discreet states' is no longer connected to learning a new physical instrument. The phrase system completely utilizes existing trumpet skill and nothing else. Learning the instrument is like learning a number of songs by heart. Single phrase songs that is.

There is a caveat. Switching from actually playing notes on the acoustic part to playing a phrase on the digital sensors has to be coordinated. Except when playing an open note with no valves depressed, the note has to be stopped in order to play a phrase on the digital valves. This involves learning a physical action and when playing fixed songs, it means learning timing similar to finding the best place to breath in the acoustic analogy.

Learning related to continuous sensors received much less attention. Three of the five continuous sensors have only recently been replaced (5.1.1.2 and 5.1.1.3), one sensor is new (5.1.1.6) and only one sensor has remained the same but with the addition of haptic feedback (5.1.1.1). Improvements are still made to improve ergonomics.

There was no serious effort to learn more precise control over the sensors that were later replaced. New implementations were sparse and control over the sensors was not very 'learnable' because of their unreliability and limited scope.

The exception was the ribbon controller (5.1.1.1). This essentially analogue sensor, was always used in a discreet manner. With the implementation of the harmoniser timing and precise control became more important. The implementation of the new Electrumpet system created more efficient message handling within the system and a new 8-core machine replacing the 4-core

original diminished bottlenecks resulting in a much more responsive ribbon controller. Timing on this sensor came within the scope of acoustic timing, especially in combination with haptic feedback. Lower sound latency on the new machine added to the improvement.

Because of all the improvements, ribbon controller timing became 'practiceable'. Practising became possible with the metronome or with a play along track to improve the synchronisation between acoustic playing and the transitions of the ribbon controller, but also to hit the right chords at the right time.

The Electrumpet system was redesigned in the first place to add the opportunity to quickly move between diverse 'discreet states', as requested by the improviser persona. To improve the coherence of the system 'discreet states' were organised in a particular manner to help the player keep his/her bearings within the system. This multidimensional approach further discussed in 5.4.3 also helped to create an easier to learn system.

Not part of the design of the instrument itself but still related to it is an aspect of learnability mentioned by Sarah Reid. "I'd love to get to this point where.. just like I pull my trumpet out to practice it every day I pull MIGSI out every day to practice and just explore that. That's a really important level that I haven't gotten to yet." (Appendix A.8). After that exchange the Electrumpet system got permanently installed in the workspace. Returning from practice or a performance it is immediately reinstalled since some of the gear is needed for other operations. The only preparation needed for practicing is starting up MAX and the patch.

5.1.3 Reflection on the performer persona

True progress for the instrumentalist persona came from making a clear distinction between the strong features of acoustic instrument informed design and strong features of digital instrument informed design and profiting from both. It is not only in Electrumpet design that we see the apparently strong design desire that is directed by knowledge of mappings in acoustic instruments. Tellef Kvifte (Kvifte, 2008, pp. 1–2) for example takes the same direction acknowledging the inherent complexity of acoustic instrument mappings in relation to digital control "the controls are more complex in the sense that they in many cases affect more than one aspect of the sound". The focus then becomes a transfer of these complex mapping of analogue sensors to control parameters: "one may for example suspect that analogue variables may be more important than digital ones in the communication of expressive content in music." (Kvifte, 2008, p. 6)

This was instrumental persona starting position as well, the fundamental insight that incited the Electrumpet redesign was to take an approach from digital instrument design advocated by Sam Pluta when he said "I wanted to create a situation where I could quickly move through a large number of processing modules at will, developing a musical language out of these rapid changes in ideas."(Pluta, 2012, p. 13). Continuous parameters are still seen as an important affordance for digital expressivity but the redesign has offered opportunities from the perspective of digital sensor control just as important or, at the

moment, more important in the case of the Electrumpet; especially when using its acoustic input and the audio descriptors derived from it.

Ironically, while the 'discreet states' implementation in the Electrumpet may intuitively point to a computer science approach, in reality the phrase system controlling it is a direct translation of the embodied technique of a trumpet player.

Still an issue is the use of the fourth valve. There are trumpets and flugelhorns that use the fourth valve either for transposing the interval of a quarter or a quart tone interval. Since the player is not familiar with this use of the fourth valve there were a few choices. Learn it without having the acoustic reference, don't use it or use it in a different way. The last option was implemented where using the fourth valve is associated with either controlling sound processing or controlling note organisation. That way the three-valve speed and embodiment can be used doubling the number of phrases. An obvious mistake that happens quite often is either forgetting the fourth valve or pushing it accidentally when time is short. In fact, the player is forced to learn manipulation of the fourth valve anyway although it is not with the same kind of virtuosity required for trumpets that have a functional fourth valve.

The period after the PhD should see a renewed focus on the continuous sensors as there are multiple improvements and new possibilities. This is not a given. Although there is significant improvement by replacing the infrared sensor with the 3D sensor there is still the issue of holding the trumpet with one hand, especially when that hand is the right hand. The 3D-sensor cannot be used for long in a row and while playing fast notes. The new 9-axis sensor with its own chosen expression limitations, the two new digital valves for the left hand and the ribbon controller are the only sensors that can always be used in combination with fluent acoustic use of the instrument.

The upgrade of the ribbon controller with haptic feedback makes it an even stronger sensor. From the designer persona's directional perspective (5.7), the danger is that other sensors are not explored with the same rigor. This is also a clear incentive to keep doing the inventorisation of sound interaction as it forces exploration of the whole instrument.

Much of this chapter is spend on sensor updates and the system. One of the by-products of the new system, the better connection, the gate microphone and a new 8-core computer is that control reliability is high sound latency low. This has made the instrument become so quick and precise that actions are now perceived as instant for two of the four sound processing modules. the other two cannot be instantaneous by their nature.

5.2 Electrumpet design from the performer persona perspective

In hindsight the performer persona was very central at the start of this PhD. The Electrumpet had been part of a very active performer practice up to then. The tension between expertise and bias was felt just as with the instrumentalist persona. The performer experience with the acoustic trumpet raised the bar of expectancy for electronic performance.

The performer and instrumentalist personas were not as clearly separated as they are currently. A description of the instrument would be a description relating to the instrumentalist persona first. Acoustic colleagues for whom performance was a given were wondered by the technical aspects and the same was true for the audience, so more tending towards the instrumentalist and luthier personas.

The interviews with colleagues operating with similar experience brought a lot of focus on aspects that are important for this particular group and this brought focus to the performance persona. An important question that kept coming up was: How is it to perform with an electronic instrument on stage? What are the experiences doing that? And how does it inform the design of the instrument?

A lot of details were given by participants related to organization and stability. Some of this relates to the instrumentalist persona but there are quite a few things typical for performing. A number of these issues were addressed in the Electrumpet redesign.

Not always is a venue suitable for a complex electronic instrument. One of the requirements of the Electrumpet's performer persona is the ability to also perform in awkward and small places without too much extra hassle compared to other musicians. As an example, one piece in the appendix was recorded in a small café in Amsterdam during the opening set of the jam session,:

Silence – Charlie Haden, arr. Hans Leeuw, Café de Engelbewaarder, May 13, 2018

The inception of the Electrumpet in itself in 2008 was a biased and personal performer persona driven issue on a meta level. Witnessing concerts in which the acoustic instrumental source was used to provide a sample for further electronic manipulation using a detached control surface did not appeal for its perceived lack of expressive instrumental integration.

One of the aspects performers in general often refer to when performing for an audience is reaching 'flow state' (Csikszentmihalyi, 2014, Chapters 15–16) to describe what is experienced when the performance is optimal. A lot of the interview participants referred to situations in which they were hindered in reaching 'flow state'. The interviews also provided best practises to optimize the instrument and the instrument setup so that 'flow state' could more easily be reached. Some of those insights are implemented in the redesigned instrument. This also became the performer persona's goal.

In 2.1.3 the importance of a personal voice was discussed in relation to saxophone player Sean Bergin. Frances Marie Uitti stressed the importance of the personal voice in her interview:

> 'But I am also interested in language, just the different ways that people develop a language, develop a voice so that after three notes you know who it is. And that can be either a composer or also an instrumentalist. Some Jazz-ers really after three notes you got, oh, that's got to be Tristan Honsinger. Nobody sounds like Tristan. And that is unbelievably great. You know there is a lot of other players and I just take a cellist but

violinist and etcetera, you... If you did not see them you would not know who is playing, you know, but people really develop their own not only sound but the way that they use it in language.'

The Electrumpet should not only be an instrument but 'the language' that it affords should be unique and recognizable. From the performance persona's viewpoint, it is an assignment to all the other personas to create opportunities. It is the task of the performer persona to embody these opportunities.

5.2.1 Development and Electrumpet specifics

The separation between the performer persona and instrumental persona has been quite deliberate, they are not completely separated though. In order for a performer to be able to reach flow state with an instrument at all, the performer has to be able to perform deliberately. The instrument should allow for that, meaning that the instrument is predictable, all its assets accessible, its functions learnable and preferably be instantaneous in its response. This all points back to aspects of instrumentality and some of the breakthroughs that are discussed in the previous paragraphs and in chapter 6. There are other aspects though that only really come forward when on stage, that are often unique to electronic and electro acoustic instruments.

5.2.2 No distraction on stage

Performing with the Electrumpet always created some anxiety. The instrument could suddenly give up on the player at the moment of an important performance. In order to have confidence in the instrument it should just work. Stepping on stage should be with a mind-set focused on performing with minimal attention to the actual workings of the instrument. Ideally the instrument would give the same freedom of use as a trumpet without augmentation does. The instrument was upgraded in a number of aspects to achieve just that.

5.2.2.1 Wireless connection and microphone freedom:

Even with the fixed microphone there was always the wish to have the instrument completely wireless. There was an element of instrumentality to it, but the ability to walk around and move could also work positively toward the audience and fellow musicians. At the PhD start, the Electrumpet used so called XBEE modules to connect to the MacBook Pro. Several updates on that particular system were made because of wireless failures shortly before concerts. It involved moving from USB to ethernet and using an external router instead of the internal MAC network.

An automated ping routine on the computer was finally added to check the network so that any cable that is not attached or half attached is immediately spotted. Only a few failures of the wireless connection at important moments still created distrust between between the performer and the instrument. That distrust does not vanish instantly when the issue is resolved.

The microphone changes are discussed in 5.1.1.4 and 5.1.1.5.

5.2.2.2 Streamlining:

Streamlining a setup means organising it in such a way that there are minimal actions of a technical nature for the performer to be taken while on stage. Joel Chadabe mentioned the importance for electronic stage performers to streamline to Anne la Berge (Appendix A.7) during one of her performances and it is part of the knowledge repertoire of experienced electroacoustic performers. Although streamlining was directed at the software setup, it can be related to all aspects of instrument setup and instrument change during performance.

To minimize setup time and cabling for the Electrumpet, the connection between the wireless connection to the computer was streamlined. The wireless router, the macbook pro adapter and the Genelec monitor speaker were integrated in one design with one power cable. Unfortunately, the new macbook thunderbolt 3 philosophy added complexity with its adapters and the inability to power sound cards over firewire. Rare wires without adapters were applied where possible.

Dismantling setups between sets or soundcheck and performance should be avoided. A few bad experiences were at the base of that assertion. All the parts of the new Electrumpet system that were not on the Trumpet itself were assembled, such that they all fit on the same microphone stand used for the Genelec monitor.

Figure 11 Microphone stand holding monitor, wireless assembly and computer

Not having the computer at table height could mean that it is hard to tend to it. A script to close other programs also starts up the wireless network, the MAX programming environment and performance patch, thus minimizing interaction with the computer. The patch itself can be completely controlled from the trumpet.

What was not really improved upon but still an issue during redesign was the ability to take the Electrumpet from its case and have it play ready within a minute with minimal assembly actions. Integrating the 3D sensor in the telephone holder on the instrument has kept the basic number of components and thus assembly time roughly the same.

5.2.2.3 Embodiment, the phrase system and closed eyes:

In the original Electrumpet system a limited number of knobs were used like they are on an average midi controller; knobs with a varying but limited assignment. Varying from one to one, one to many and sometimes these in parallel. These slightly unreliable knobs used gestures like series of double pushes on pressure sensors to control four independently controllable audio channels. Often three or four channels were changed simultaneously each with its own knob. This required continuous attention to the screen in order to verify whether a certain action was registered as intended and which channel was active in what manner. Often a few extra actions were needed to reach an intended state since for example one of the double push gestures was registered as a single push.

For optimal interaction with the musical environment, Nijs (Nijs et al., 2009, p. 6) describes flow broader then the purely instrumental control. The subjective experience is described as "(1) the merging of activity and awareness (2) complete concentration on the task at hand, (3) a sense of potential control, (4) a loss of self-consciousness and (5) an altered sense of time"

Playing the acoustic trumpet, this description was immediately clear especially when relating it to the stage performance. For the original Electrumpet system it wasn't. None of the five mentioned descriptions matched, although brief flow periods happened when only working with one continuous sensor. Closed eyes were often an indication of playing trumpet without self-consciousness acoustically. On the old Electrumpet system this only happened for brief periods playing one continuous sensor at a time.

The new phrase system afforded for close eyed playing accessing much of the instruments total capabilities. Close eyed playing was no goal in itself. It could now be used though to check on badly mapped phrases but more importantly the eyes could be used for other activities like looking at other players or the audience and in theory sheet music. The instrument itself needed much less attention that could distract. There was still a telephone screen for visual feedback on the instrument mostly for assurance. For some actions though, where parameters in the system were changed through a series of phrases without auditive feedback, the screen was still necessary.

5.2.2.4 Repertoire

Where flow is sub-conscious and should contribute to the positive feeling with the instrument on stage, that is not the only factor according to Nijs (Nijs et al., 2009, pp. 7–8), that contributes to a positive experience on stage. Presence-as-process allows to control behavior on the basis of the awareness of an inner and outer world.

Repertoire was the most prominent confidence factor for the Electrumpet while on stage that did not relate to a functioning embodied instrument. Insufficient repertoire was undermining that confidence, especially in an open improvisational setting. For the player, to experience the instrument as meaningful its repertoire had to grow.

Developing musical meaningfully material specifically devoted to the instrument that would go further than the proverbial bag of tricks was always complicated because of the inefficient structure of its system. While the harmoniser seemed to be adding repertoire to the system it also stagnated development. The instrument developed a dual musical identity with on the one hand experiments that related to sensor interaction with sound processing and on the other hand an often-traditional sounding implementation of live electronics through the harmoniser.

The main boost in repertoire for the new system came through the influence of the improviser persona. The multi-dimensional approach in particular made it possible to have an exponential field of opportunities, while at the same time keeping the number of building blocks fairly limited. This also made it possible to blend the dual musical identities that were at the root of its stagnation. It significantly increased the confidence in relation to its now expanded repertoire.

5.2.2.5 Being prepared and testing

The home practice situation for the Electrumpet was and is slightly different from the performance situation. The screen on the instrument only has stage usage, there might be different cable. Checking the gear before leaving for a performance is wise practice especially in cases where there are long breaks of inactivity between performances. Vulnerable issues on the Electrumpet were unexpected software updates of the VNC-app for the iphone, rare cross cable ethernet issues, gear that was left at home etcetera. Pluta in his interview (Appendix A.1) saw setting up and breaking down as practising.

5.2.3 Context and appearance

Hyper instruments do not belong to a certain defined niche like traditional instruments do. They are not even established in a way that analogue synthesizers or even electric guitars and synthesizers are. Unknown prejudices towards the instrument and its player might surface the moment a hyper instrument appears on stage in a more traditional setting as they are not established yet. Hardjowirogo (Hardjowirogo, 2016, p. 21) calls these aspects “Immaterial Features” or the Cultural Embeddedness of instrumentality.

Prejudice is dependent on context. Taking long to setup in an acoustic setting is no issue for a drummer for example. A hyper instrument player on the other hand using a lot of gear and cables will be met with a certain suspicion. Streamlining as mentioned in 5.2.2.2 also helped in the first impression that the instrument made. It dealt with subconscious public questions concerning the professionality as a musician.

To increase acceptability, the new Electrumpet used even more natural and handcrafted materials then before. Using wood and metal features, exclusively brass, and removing some excessive knobs, the instrument got a friendlier 'analogue' look, while at the same time harbouring more advanced technology.

5.2.4 Reflection on the performer persona

The performer persona definition is quite broad as it relates to the design of new musical instruments. It encompasses practical issues that can interfere with the confidence with which an instrument is played on stage. These issues surface in the designing phase of an instrument especially.

As we saw in 5.2.2.4 it was possible to shift the focus from the instruments physical functioning and appearance to the development of a versatile repertoire. It changes from 'will it be possible to say something' to 'will it be possible to say something meaningful'. In that sense it is like moving up the pyramid of Maslow's hierarchy of needs.

Tackling physical and technical issues will probably always remain an issue with the Electrumpet. It is good though to notice, that their influence on the development of the instrument has decreased significantly during the course of the PhD. There is a much healthier interchange between the performer, instrumentalist and composer persona. These are all the personas on the left side of the persona model and they all handle story / time-based aspects (see 3.3.1).

5.3 Electrumpet design from the luthier persona perspective

While the classical luthier or instrument builder is often a very fine wood- or metal worker, the luthier persona in the case of the Electrumpet actually exists of three sub personas that could almost be seen separate. Here they will be called the 'sound luthier', the 'hardware luthier' and the 'artisan luthier'.

Each of these personas can have its own position regarding the Electrumpet but there is certainly also a general artistic position towards the instrument that can be applied from the perspective of all these personas. The Electrumpet is an augmented trumpet and much effort goes into staying close to the original instrument if possible.

As an example, the original idea for the voice synthesis module comes from an acoustic technique on the trumpet called growling that is performed with the plunger mute and made famous in the Ellington band, particular in pieces with a unique sound called 'jungle style' (Hannon Teal, 2012, p. 130). The challenge was to see if the typical jungle sound 'wah' sound could be replicated and expanded

on. The first attempts were to build a vocoder like transformation from trumpet sound to vowel. There remained too much of the trumpet sound though. A new attempt within the PhD period used the zero crossings of the trumpet sound to do actual voice synthesis. The vowels are controlled using a loose hand before the infrared sensor emulating an interaction similar to the plunger mute moves at the trumpet bell.

This is a sound and interaction example but looking at the artisan luthier we see the preference for natural materials in an attempt to soften the overly technical elements of the instrument. We also see it in the placement of the sensors which are preferably not interfering with the normal way a trumpet is held.

5.3.1 The sound luthier

Within the sub persona of the sound luthier, there is even a further subdivision that truly emerged within the PhD period. There is the creative sound processing aspect but there is also a craftmanship aspect that used to be neglected. The acoustic musicians background unconsciously separated the sound coming from the instrument in interaction with other musicians from the sound coming from the speakers for the audience, the latter traditionally being the responsibility for the sound technician. Especially when working with different inseparable layers a sound technician cannot make an electronic instrument sound good on stage when the original signal is flawed though.

The naive sound awareness at the beginning of the PhD can be clearly heard in the recordings from that period in the appendix. There is no clearly defined room and most peculiar, the voices move through space while it is clearly some kind of brass quartet playing. (Appendix G.5.4.1)

This awareness though latently present was more deliberately developed in the further development of the old Electrumpet system from 2014 to 2017 during the PhD. Due to the poor organisation in that system though that task was complicated. Because the system was not modular, a change at one part in the system could lead to a weakening of the overall sound quality or the necessity to add extra control management.

In the new Electrumpet system, the organisation was improved such that there was much more control over parameters that can influence aspects of sound quality like clarity, balance, spectral mix, compression and spatialization. Presets governing sound output quality were linked to the system governing harmonisation and the current sound processing technique. There were also improvements made within specific voices dealing with sound processing that were of major influence to the afore mentioned aspects of sound quality.

Sound is not only a question of quality, but also a question of artistic choices. A fundamental Electrumpet choice is that trumpet sound is always controlling the instrument. Sound processing that references the sound input in a recognizable way is sought. A transformation may be very removed and experimental though. Intelligent original sound processing implementations are favoured over solutions that can be used out of the box. These original solutions often use

recognisable and controllable sound descriptors and other features derived from the trumpet sound input.

Although the goal for the Electrumpet is a new form of interaction, it certainly falls within a tradition. Inspiration to start the project years ago came from Edwin van der Heide and his MIDI-conductor (Bongers, 1998, pp. 16–17) which in turn was an adaptation of Michel Waisvisz 'the hands' (Krefeld, 1990), the latter developed STEIM's LiSa system for live sound sampling used by other artists related to STEIM. Alex Nowitz (Nowitz, 2008) embellished the system further, first using WII controllers and later a dedicated instrument developed at STEIM. Andy Otto, also related to STEIM, uses a self-developed sensor augmented bow called 'Fello' to control looped back phrases in a coherent fashion with his own playing using improvisation. Jérome Nika developed Improtek (Nika & Chemillier, 2012) a system that can play back timed phrases based on fixed chord changes to the performer and is suitable within Jazz improvisation.

Compared to the new Electrumpet system the examples mentioned in the previous paragraph are more focussed on recorded sampled sound, sometimes whole phrases. The current approach is closer to what happens in Diemo Schwarz' CataRT (Schwarz, 2004) concatenating single sounds together into new phrases. Time wise there is a close connection to what the acoustic trumpet plays and the resulting sound more similar to what happens in guitar effect pedals. Since the Electrumpet is almost completely buffer based, a mix between the current approach and longer recorded phrases is possible. The close relation with the current Trumpet sound is the focus of the sound luthier persona as it is most suitable for quickly moving free improvisations.

Relevant improvements related to the sound luthier sub persona are discussed in the next paragraphs.

5.3.1.1 Harmoniser balance and quality

Within the interactive harmoniser some balancing techniques were implemented 'intelligently' on a single voice basis. In the delay line transposition for example used for downward transposition, the fundamental of each tone was suppressed using a filter with a cut-off frequency controlled by the frequency of the incoming tone. This significantly reduced masking by these fundamentals and resulted in a much clearer harmoniser sound. Sinusoidal tones in general easily mask higher tones especially at higher volumes (Roederer, 2009, p. 87). It also made the instrument much less intrusive when playing with others. A similar attenuation of overtones in relation to the current pitch was implemented elsewhere.

This is not only a technical issue. The clearer harmoniser sound was more appreciated with time and shifted the aesthetic preference towards it. This experience was very similar as learning the appreciation of a good acoustic trumpet sound while making it years in the past.

Another balancing technique tackled the strength of each individual voice in the harmonized sound. It became individually dependent on its transposition factor

but also on the number of voices active. Each individual voice's volume became reversely related to the total number of voices. A feature not implemented in arpeggiated mode.

5.3.1.2 'post-processing' tools

A hyper instrument player may be more 'helpless' in controlling his or her final sound coming from the speakers than a player that can have a separate interface fully dedicated to the issue. Still, as was discussed in 5.3.1, part of the responsibilities of the sound engineer have to be integrated in the instrument by the instrument designer. To a certain degree automation could overcome this handicap by creating particular sound palettes for each 'song' and situation. The modular approach of both IRCAM's SPAT (Carpentier et al., 2015) and the new Electrumpet system helped the implementation. A combined visual interface for tuning, spatialization and room features, created overview.

5.3.1.3 Sound processing tools

There are many soft- and hardware tools provided in electronic music. The appreciation of the artistic outcome does not necessarily have any relation with the tools that are used though. For some niches, like live coding, the analogue synthesis community and robotics, technological aspects do play a role in audience appreciation. The measure in which the self-development of tools is determined by the luthier persona. Interview participants talk about balancing time between maintaining a professional life as a performer/composer versus spending time on technical issues like maintaining or improving the hardware instrument, "using fancy sound processing" or designing a dedicated system in software.

Considering the Electrumpet that choice is driven by the system and interaction. Instead of building a portfolio of separate design and/or composition processes, there is one iterative process that should lead to an instrument with the capability of producing that vast repertoire from its range of possibilities through improvisation. Pride is taken in truly unique sound interactions that can be used, reused, altered and adopted as opposed to one brilliantly conceived piece. Hence also the term composing from the instrument discussed in the composer persona paragraphs.

Pride in unique sound interaction does not mean that everything has to be designed from scratch. On the contrary, well designed sound processing tools that can easily be implemented in the system are welcomed. As a programming and sound processing environment the Electrumpet uses MAX with a large role for FTM&Co (Schnell et al., 2005), Bach (Agostini & Ghisi, 2013) and DynamicDSP (Harker, 2011) because of their organisational features that helped enormously in improving the organisation of the Electrumpet system.

The MAX programming environment was already chosen in 2008 for its affordance for tinkering interaction. Another advantage of MAX is the large amount of extension possibilities within that environment. The Electrumpet especially benefits from externals and libraries that have been developed at the IRCAM institute in Paris (Ircam, 1998) and shared with its community. These

tools are dedicated to be used in an environment with acoustic instrument input and live interaction. The tools are developed with composers and instrumentalists in mind making the way they interact logical for this kind of user. At the same time these tools are highly advanced, complex and with a lot of their features accessible as controllable parameters so they can be personalised according to artistic taste.

Momentarily the sound processing choices centre around the construction of the system. Sound processing tools that could be used directly on the incoming sound and/or implement some form of analysis resynthesis were the basis for the redesign. These tools could be used in the harmoniser, the central feature in the control of pitch organisation for the moment. Although other forms of organisation, e.g. corpus-based synthesis, concatenative synthesis on past events, some forms of loops, were definitively looked at, exploring sound synthesis based on the harmoniser had enough possibilities and unexplored territories to dive into.

In the current Electrumpet system five types of sound processing on one incoming buffer using MuBu (Schnell, Röbel, Schwarz, Peeters, & Borghesi, 2009) were implemented, two of them in a combination. Each of these types was implemented on twelve channels each with their own controllable set of parameters for transposition, volume, OnOff, dynamic and static filtering, delay or playing position and a one-dimensional 1-n mapped general sound synthesis parameter. Each of these twelve channels optionally could be processed in a second layer of processing currently consisting of two additional processing techniques also related to harmonisation.

Two of the sound processing types were optimized for low latency, a phase vocoder (Bogaards, Röbel, & Rodet, 2004) delay Line combination and voice synthesis based on zero crossings in the trumpet sound. The latter two were designed with a similar unique technique for transposition utilising onset and pitch change detection mixing two delay lines. These techniques were taxing on the processing capabilities of the computer thus impacting latency negatively, but after an upgrade to an 8-core machine the latency for both techniques was even manageable for high speed timed playing. It should be noted that horn players are used to a certain amount of latency before a tone is established in acoustic music as well (Howard & Angus, 2017, p. 240).

The other two sound processing types used on the incoming buffer were less suitable for timed harmonisation. They were suitable though for implementations where the harmoniser is used for soundscapes or in a more ornamental way. Analysis and additive resynthesis was implemented using a self-designed system since there was no implementation in MuBu yet.

Sam Pluta talks about the use of quick mixing and routing changes as a means of expression (Appendix A.1). The effectiveness of that strategy is clear in his performances. A similar implementation was not directly possible on the Electrumpet. For that ultimate purpose though the fairly complex sound modules in the electrumpet were all made suitable for the same parameter input. Flexible routing though would mean that different modules could be put after each other in arbitrary fashion.

The modules in the second layer of sound processing were a first exploration in that direction. Not the incoming sound buffer but the twelve outgoing channels of the first layer were their input. Potentially they could be used in series with a new upgrade of the system.

Thus far these second layer modules were both implemented using some of the parameters used in the first layer modules, OnOff and pitch, and globally controlled parameters. Combining the transposition capabilities of the first row with smart ring modulation resulted in octave doublings keeping the original harmonisation more or less intact. Similarly, another second layer module implementing physical modelling afforded for tuned virtual plate and other bodies reverb possibilities. The next movie contains some sound processing variations including the second layer modules.

Demonstration improvisation using diverse settings.

5.3.1.4 Psychoacoustics and subjective perception

The sound choices described in a number of the previous paragraphs are often strongly related to the perception of sound and thus psychoacoustics. The application of psychoacoustics within the instrument got developed. Apart from the masking and sound volume related descriptions in previous paragraphs it also came back in other aspects more related to composition.

Examples in the context of the harmoniser:

- The limit of frequency discrimination and Just Noticeable Difference for pitch in a harmonisation inspired by 'Critical Band' by James Tenney (Tenney & Gilmore, 2019, p. 494)
- Harmonic harmonisations tuned according to Just intonation in adaptive tuning. (Sethares, 1994)
- The arpeggiated mode that was split in a delayed mode (delay times > 100 ms) where notes could be heard as individually delayed and a strumming mode (chosen delay time 50 ms) where the arpeggio sounded as just one sound gesture.
- Auditory stream segregation in the arpeggiated mode. (Bregman & Campbell, 1971)

Psychoacoustics also influenced the handling of latency within the harmoniser. It takes 10 – 20 ms for a trumpet sound to build up through the acoustics of the instrument (Howard & Angus, 2017, p. 240). It also takes some time to establish the correct pitch with the auditory system. Typically sinusoidal tones take 8 cycles under 1000 Hz and 8 ms above 1000 Hz according to Pollack (Pollack, 1968, p. 167). It is unclear how long the perception of complex tones, like that of a trumpet, takes but it is probably longer then 8 ms. Both these effect's contributions suggest that it is ok to have some pitch ambiguity at the onset of a tone.

Tests establishing accepted latency with wedge monitors testing saxophone players may indicate what latency is accepted regarding onset for trumpet players as well. Lester and al (Lester & Boley, 2007, p. 709) found that on a

subjective scale ranging from excellent to good, fair, bad and horrible, a latency of about 20 ms was still considered good by most participants. The sample was very small though.

Measured within the MAX patch, onset detection is often much quicker than pitch change detection. Varying from 40 to 200 ms for the trumpet. In the Electrumpet onset detection determined the timing of attacked chords. When a note with a clear attack changed in transposition, the 'old' transposition was used for that note until a 'new' pitch could replace it. A clear pitch shift would only be heard in case of a relatively long period between onset and pitch recognition.

5.3.2 The electronic hardware luthier or electronic engineer

Both the electronic hardware and the artisan luthier are personas that are not constantly present in the design process of the Electrumpet. They both get active when a new physical version gets manufactured, sometimes to repair a part or to improve on something physical or electronic. The electronic hardware and artisan luthier personas have both been active in the PhD period though since a new Electrumpet prototype was manufactured.

There are three main topics when choosing electronic hardware for the Electrumpet: which sensors and actuators to choose, how to implement the wireless connection and which platform forms the core of the system? The choice to be wireless already made by the performer persona.

Important hardware considerations that were incentives for updates were reliability, longevity/sturdiness, versatility, time resolution, latency, ergonomics and usability in performance situations. Often these were requirements from the performer persona but an assignment for the hardware luthier. Apart from typical electronics skills the hardware luthier persona working on musical instruments should be typically aware of timing issues and time magnitudes as they relate to latency, resolution and jitter but also how they relate to typical instrumental needs. A sensor that is related to a timed staccato attack has to be more precise in timing then a sensor related to legato transitions for example.

5.3.2.1 Sensors and actuators

Quite a few sensors were replaced in this new Electrumpet version or even dismissed all together due to the total system redesign. Some hardware redesign was based on ergonomics and some was based on newly available hardware. The digital valves and the ribbon controller were already present in the previous version. They have both been proven reliable and sturdy although some of the connections were improved upon (see 5.3.3).

New was the use of the GestIC sensor (Microchip, 2012). This sensor replaced the infrared sensor to estimate a hand position above the trumpet bell. The GestIC sensor can track the hand position in 3D. Its time resolution of one measurement in 10ms is about twice as fast as the infrared sensor. The interaction with this sensor is mostly not very timing dependent though. There are extra opportunities for interaction since the sensor is also a 2D multitouch

sensor. The infrared sensor had to be replaced since it's use was limited due to infrared light interference, especially on stage.

Also added was a 9 degrees of freedom sensor (Bosch, 2014). It can measure both the orientation of the Electrumpet in 3D space and the acceleration of the instrument, also in 3D. Its time resolution is also 10ms.

A gating mic was also added to the instrument (Francis, 2013). Isolation of the main microphone from non-trumpet audio input, was its main design incentive but pitch, volume and onset detection on its audio input was implemented as well. Gating prevents the processing of the sound of other musical instruments present and feedback.

5.3.2.2 Wireless connection

Over the years, wireless connection opportunities for digital instruments and controllers have changed. NIME literature on the subject by Mitchell (Mitchell et al., 2014) suggested that WIFI was the most viable option available when not used in the overpopulated 2,4 GHz frequency band. Furthermore, it advised using a directional antenna to limit interference from other nearby wireless senders. The base station of the system became a powerful antenna / router system suitable even for outdoor use (Ubiquity, 2005a)(Ubiquity, 2005b).

5.3.2.3 'Embedded' system

In order to combine 5GHz Wi-Fi and the GestIC sensor technology a microcontroller could no longer be used to integrate the system on the instrument. The first platform that was chosen, the Edison from Intel, became obsolete during the development of the system. It took a while for another small suitable platform to emerge. The PocketBeagle (beagleboard.org foundation, 2017) both had the size and the specifications for successful Electrumpet implementation. For the WIFI sender on the Electrumpet itself a suitable USB-dongle was chosen. The PocketBeagle came with the extra advantage of an integrated microcontroller which made it possible to sample sensors and even sound with great temporal accuracy.

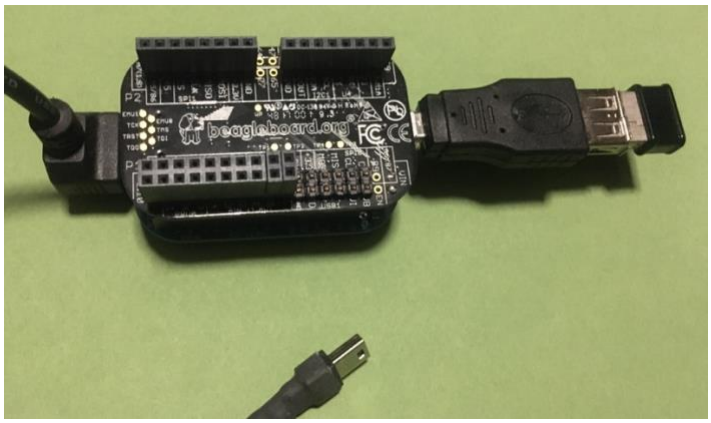


Figure 12 PocketBeagle including the headers attaching it securely to the main Electrumpet PCB board. Also visible is the USB shield for USB peripherals like the 3D touch sensor. A Wi-Fi dongle with adapter is also attached.

5.3.3 The artisan luthier or instrument maker

The artisan luthier persona concerns physically making instrument parts. The development of new manufacturing techniques and the development of the DIY culture in the last ten to twenty years has brought big opportunities for the self-manufacturing of digital and electro-acoustical instruments. This development has partly come back in the new hardware version of the Electrumpet. The exact form of the new parts is often informed by the performer and instrumentalist personas, where the instrumental persona informs ergonomic considerations.

Integrating new hardware useful for the instrumentalist persona's abilities for intuitive and embodied play were to be combined with better ergonomics and reliability the latter being a performer persona criterium. Sensors preferably do not interfere with the normal way a trumpet is held. Similar considerations can be seen in the trumpet extension MIGSI (Reid et al., 2016, pp. 420–421) built with the idea of minimal invasiveness. Ben Neill on the other hand uses a controller with a clearly visible PCB board and a midi controller style interface with colourful knobs. (Neill, Moog, Behrman, & Abraham, 2017)

Holding the instrument with only the right hand is required to be able to play notes and play the distance sensor with the left hand simultaneously. This should also be reasonable comfortable.

Aesthetic considerations were addressed in materials using pear wood, which lends itself for fine woodworking and has a nice professional look, and brass the quintessential trumpet material.

Material awareness and consideration for aesthetic detail were influenced through the connection with the Industrial Design faculty of the Technical University Eindhoven. This kind of influences outside the frame of music and music technology were also mentioned in the interviews with Rajesh Mehta, Sarah Reid and Sam Pluta (Appendices A.1, A.8, A.4)

5.3.3.1 Brass frame

The basic construction of the Electrumpet did not need a change. The new Brass frame is much simpler though than the former Electrumpet frame, that needed a lot of holes for knobs and a section on the side that held knob assemblies. The new frame looks sharper than the old frame, since it was manufactured with a CNC waterjet. Especially for square and small holes this was a major improvement and added to the stability of the frame. The layer between the PCB protoboard and the brass frame which was a consideration in the old version because of current leakage was replaced by EVA foam, a popular material for CNC manufacturing, that is both thin, flexible and sturdy. Loose nuts, bolts and plates, all in brass were assembled into a sturdier and better looking fixing of the frame on the trumpet.

The rounded edge of the frame was deliberately kept low. The previous frame cut into the right hand when playing the instrument with one hand.

Figure 13 top brass plate and brackets that fixate the plate on the trumpets lead pipe

5.3.3.2 New digital valves

Four digital valves were already on the instrument to resemble the acoustic valves of the not augmented trumpet. Two valves were added as a replacement for two pressure sensors that were attached to the third valve. All digital valves were hacked with some felt in the sensor and under its attached knob; this to reduce metallic noise sounds while at the same time giving a more smooth and natural feeling comparable to 'real' trumpet valves.

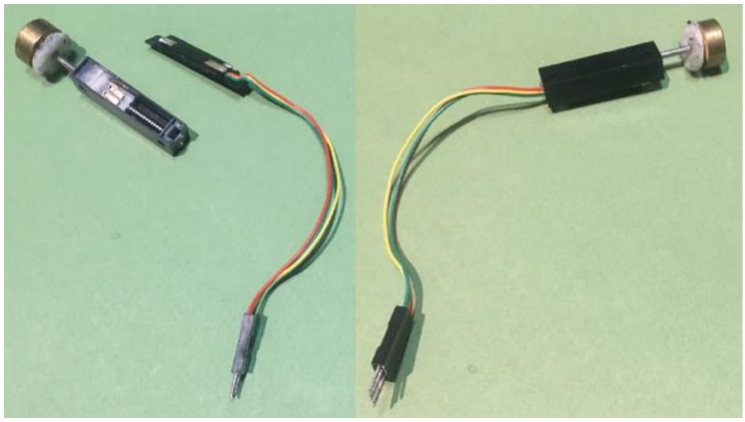


Figure 14 valve: In the left picture the valve is open, showing felt inside, and on the right as it sits on the Electrumpet.

The attachment of the digital valves was 3D-modeled and twelve slightly different models were water cut so the best version considering ergonomics could be chosen. Despite this major upgrade the support for the fingers of the left hand is still worked on. The weight of the Electrumpet pushes the fingers together so they can't freely move.

The attachment for the new digital valves is the first part of the Electrumpet that is actually soldered onto the trumpet itself. The idea to use the square brass supports stems from an earlier augmentation implementing a microtone slider.

Figure 15 Left: bracket soldered on trumpet, right: valves that replace the pressure sensors attached to bracket

Figure 16 all digital potmeters on the trumpet. The upper four valves are played with the right hand, the bottom two with the index and middle finger of the left hand.

5.3.3.3 New casing for iphone and Gestic sensor

As was discussed in the instrumentalist persona (5.1) the new GestIC 3D position sensor replaced the 1D infrared distance sensor. The logical place for this sensor

was the backside of the iPhone. Aesthetic reasons but also the need for sturdiness were incentives to make a wooden casing that could hold both the sensor and the phone. Sturdiness is the main reason to design the lyre holder in such a way that the attachment is completely inside the casing, but it is also aesthetically pleasing. CNC milling was used to create the casing from pear wood. It is light, sturdy and easy to mould. Pear wood veneer was glued to the backside of the 3D touch sensor for aesthetic reasons.

Figure 17 Upper row: back panel outside, inside and with PCB. Middel: front panel inside with bracket removed and attached, Bottom: complete assembly backside and frontside without phone

5.3.3.4 New casing for ribbon controller and haptic motors

An ABS-plastic holder for the ribbon controller was always the uglier part of the old Electrumpet. It was replaced by a similar holder manually made out of pear wood adding the opportunity to carve out special holes for the placement of haptic motors. The haptic vibrations were also an incentive to make the inside electronics sturdier with a solid electronic connection of custom bend pinheaders to the rest of the system in order to prevent acoustic noise.

Figure 18 Ribbon controller assembly inside and outside view

5.3.3.5 Assembly of the new physical Electrumpet

All the upgraded elements of the Electrumpet were integrated in a new physical instrument. That also offered opportunities to tackle some annoying details from the past version. The attachment of digital valve wires was redone for easier connection to the PCB board. The wires now follow a path that does not interfere with holding the instrument.

All the other elements on the instrument were carefully placed to leave ample room for the left hand to hold the instrument and for the thumb of the right hand to go in between the first two valves for counterbalance when the valves are pressed.

Holding the instrument with the right hand so that the left hand can be used to play the Gestic sensor, at the back of the wooden casing, poses a problem because the new potmeter sensors for the left hand will be pressed.

Figure 19 right side of the new physical Electrumpet

Figure 20 left side of the new physical Electrumpet

5.3.3.6 Attachment frame for antenna, router and MacBook power adapter

Not only the instrument that is held and has all the sensors, microphones, actuator and computing gear attached to it needed to be built physically. The wireless assembly (5.2.2.2) was also manufactured for better streamlining. Loose parts were integrated where possible for easier setup and compactness. A holder for the wireless base antenna and router was welded on the bottom part of a microphone stand so it could slide over the upper part of a microphone stand at a venue. The clutch was not removed but instead functions as a fixation of the assembly on the microphone stand at a certain height. The whole assembly was painted black, the colour of most modern microphone stands.

On this part the cabling of the antenna, the router and the power over ethernet adapter are fixed together. Since both the Genelec monitor and the macbook pro are always part of the Electrumpet setup as well, their powering has been integrated in the assembly. The power part is protected by a vacuum formed enclosing.

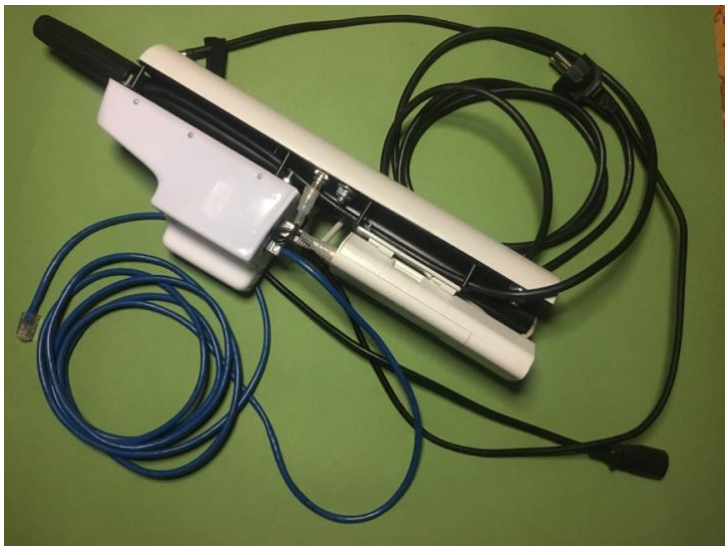


Figure 21 Antenna and router assembly with attached cables for power, powering the genelec, powering the MacBook and ethernet to the MacBook

5.3.4 Reflection on the luthier persona activities

At the start of the PhD period it was not a goal to change the instrument itself so dramatically. A major system redesign was inevitable though and it was logical to finally upgrade the physical instrument as well to bring the expressive capabilities of continuous sensors up to par with the new system. Redesigning the instrument has taken a lot of thinking and effort and ultimately the luthier persona has been much more active than anticipated as a result of it.

There are positive and negative sides to this. Clearly the instrument as it has been developed has grown up. Both sound wise and in its interaction and possibilities it is positively incomparable to where it all started. The redesign and before that the stagnation in development has taken away energy from other personas though. Too much effort went into details of the instruments sound satisfying the luthier personas direct interest while a fundamental redesign made much of that effort moot. The luthier persona served as a distractor while the improviser and composer personas were stuck and the designer persona did not have a solution yet. Meanwhile the tinkerer persona transformed the system or better patch more and more into something unchangeable and unorganisable.

On the bright side, now that the instrument has found a form in which it can develop into the foreseeable future, some of the luthier tinkering experiments have found good resolutions in the new system. The awareness of especially the 'sound luthier' has evolved considerably. The awareness for sound output quality, balance and internal masking makes a huge difference in the sounding result.

There are still steps that were not made from the perspective of the sound luthier. Song harmonisation presets are linked to the control of output sound parameters but there is no general system that governs how this automation of output sound parameters is influenced by the performance venue acoustics and its amplification system.

Apart from the 'sound luthier' persona, the 'electronic hardware luthier' and the 'artisan luthier' have been developed as well. In the case of an eventual next physical version it might be wise to consider sourcing these two tasks out or at least share them with another developer like it is done with the Sabre (Schiesser & Schacher, 2012) which is a team effort. There is a danger to completely outsourcing part of the development as knowledge needed for upgrading and repair may vanish with the external developer.

While the 'sound luthier' is clearly intertwined with the other personas in the model, the 'electronic hardware luthier' and the 'artisan luthier' personas are more separate. They mostly get active when designing a new system and when that happens it is hard to keep the musical development of the instrument at a pace. This depends on the complexity of the effort. The complexity of the last physical upgrade was again higher than the previous one in 2012 and the loss of attention to other personas considerable. It is a dilemma that musicians who built their own instruments mention as an issue or try to avoid if we consider the interviews representable. (Appendix A)

5.4 Electrumpet design from the Improviser persona perspective

The improviser persona's view on improvisation as it relates to the Electrumpet encompasses two distinctive positions. First, improvisation is related to harmonically bound improvisation in what Ron Miller describes in his book as "chromatic-modal harmonic system using free-asymmetric form" (Miller, 1996, p. 6). This harmonic form was often combined with rhythmic influences and form derived from Indian Carnatic music (Reina, 2015). Both books of Miller and Reina offer methodology to learn specific methods for improvisation and composition and are key parts of the composer/improviser persona background related to the Electrumpet. Second, improvisation is related to a Dutch school of free improvisation sometimes called 'Dutch swing' (Whitehead, 1998) and in particularly present in the Electrumpet's residence Amsterdam. The Electrumpet's past practice was a mix between these two seemingly very different directions.

That is not only true for the Electrumpet itself, but was also reflected in the artistic profile of the band Tetzepi in which it operated. Tetzepi was the 15-piece professional and structurally funded big band that was led by the author between 1996 and 2014 and during that time the main artistic activity (Tetzepi, 2011b). The more theoretical approaches described above were worked out in complex grooves with an important role for a bass section within the band relating to the Carnatic influence. In Tetzepi that often meant doubling the bass part with the baritone saxophone and the bass trombone or Tuba and the electric guitar enhanced with distortion and octaver. These pieces were typically through composed with certain sections open for improvisation based on a groove with some form of modal progressions.

Free improvisation was also practiced within Tetzepi. It could be part of dedicated pieces aimed at this form of improvisation, but even through composed rhythmical pieces could contain sections with total improvisational freedom. Basically, the improvisational descriptions of the first paragraph were strongly rooted within the band, but there was no strict adherence to it. Coherence in repertoire was reached by choosing composers, often commissioned, that operated from a similar background or were (ex-)members of the band.

The Electrumpet was only partly able to operate within this environment. Its electronic capabilities were only used in certain sections, none of which were of the complex rhythmical kind.

Improvisation within a rhythmical context goes further than the role of the soloist. Within a Jazz context the rhythm section also improvises its accompaniment. Within Tetzepi sections of collective improvisation based on rhythm happened as well, sometimes including the Electrumpet. In the accompanying example you can hear how this sound wise could work but timing wise was an issue. In this case it is more or less a duet between the Electrumpet and part of the rest of the band. The electronic manipulation of the sound uses the IRCAM vocoder (Bogaards et al., 2004) with non-pitched sounds and even some voice input at the end of the intro which at about 3'30".

Sous Influences – Gilles Coronado, arr. Hans Leeuw. Recorded: March 2, 2013, Lantarenvenster Rotterdam

Continuous sensor control on certain aspect of an effect was certainly an asset but also limited in its scope. It was only used within a certain preset and in that sense one dimensional even while 'one to many' or divergent mapping was used (Rovan, Wanderley, Dubnov, & Depalle, 1997, p. 69). In this case a filter sweep, transposition and volume on the pressure sensors and the tonal mix of the phase vocoder resynthesis on the infrared sensor.

Another example of a more or less 'single purpose' instrument accessible in the old system and used in the context of Tetzepi was analysis combined with additive resynthesis to pick out the overtones of the trumpet sound using the infrared sensor. The distance of the hand to the sensor corresponded to a particular overtone. Using a hand or plunger mute to filter the acoustic trumpet sound was its inspiration. Here it can be heard and seen in a duet with French bass clarinettist Louis Sclavis in the intro of a piece of Jorrit Dijkstra: Break? Dance!

Overtone use on Electrumpet in 2013 TV program 'Vrije Geluiden'

Although there were more interactions implemented, the repertoire was limited and playing the instrument sometimes felt like picking one of the tricks like the ones above instead of having a real instrument.

Within Tetzepi there was also room for more free improvisation without clear predetermined agreements and with room for sound exploration. This was reminiscent of the other major context in which the Electrumpet was used: duets and trios in different settings. Instead of another example of Tetzepi here an example of a duet with Diemo Schwartz also around that time. Again, the vocoder and transposition play an important role. At about 0'50" a different setting of the vocoder is made on knobs on the side of the instrument that have since vanished. At 1'10" knobs are pushed to get to the right record setting. These knobs have also vanished. Recorded sounds could be played with the extra mouthpiece and placed into a loop. At about 3'00" where recorded sounds are fed through the vocoder in a high tempo with an extreme setting. The tempo in which settings are changed through the piece is slow and similar processing keeps coming back from the Electrumpet. Variation has to come from CataRT, Diemo Schwarz' instrument. For reference this recording is also in the folder with recordings (Appendix G.5.4)

Video of duet with Diemo Schwarz in 2012 at STEIM

5.4.1 Improvisation on the Electrumpet, state of the art at the start of the PhD

At the start of the PhD it seemed logical to continue expanding on the use of continuous sensors for interactive and expressive control of effects which could then be used mainly in free improvisations and maybe for percussive uses.

The interactive harmoniser was also invented right at this time though. The combination of pitch recognition and discreet interaction through the ribbon controller provided the kind of new intriguing interaction that was also very

interesting. It seemed such a huge asset for the instrument at the time that it overtook much of the time spend on development. It had to be explored. It also gave opportunity to have more possibilities in the hybrid practice described in 5.4. Some of the recordings made during that time are part of the submitted work folder. (Appendix G.5.4.1a). Clearly the harmonisation is not as smooth as the short counterpoint example made recently (see 5.6.2). Improving the technical implementation took a lot of time especially in the old system.

Within concerts the instrument was mostly not used as literally. A little later in the PhD the harmoniser could already be used a little more creatively in a duo with Diemo Schwarz. Additive resynthesis could already be combined with the harmoniser (Appendix G.5.4.1b). The recording is called Paris Folk Song from February 21, 2016.

The ability to use controlled chords in a timed manner opened new opportunities for a musical role normally only available for chord instruments and that in a truly unique manner. Jazz improvisation in typical oral conversation would imply the soloist that is improvising but depending on the musical style there can be a lot of improvisation in the accompaniment as well. The more collective approach where the rhythm section was not subservient to the soloist was typical for all past artistic musical projects and the harmoniser opened up a lot of opportunities in that specific role as well.

The harmoniser also gave the prospect of using it on a few horns thus creating a small horn section that could improvise a Big Band backing arrangement. This has not yet been implemented.

Within improvisation there was no clear idea of what expressive instrumental control on a hyper instrument should be in relation to the Electrumpet. There was the issue of being quick and the issue of being expressive but they were not as such clearly separated yet. Expressive then associated with continuous connection to sound control.

Concluding, there was a small wish list at the start of the PhD regarding the ability to use the Electrumpet within improvisation but not a clear direction:

- Expand on the number of expressive interactive effects controlled with the continuous sensors
- Expand on the number of musical roles that the instrument can take especially roles that are not traditional trumpet roles, like base and chord instrument, with the interactive harmoniser invention.
- Learn better control within an improvisation context using the Electrumpet.

5.4.2 Improvisation, evolution and new gained insights during the PhD

Before conducting the interviews, the premise was that virtuosity in improvisation could be approached very similar to control over improvisation in an acoustic context and that the acoustic background as a virtuoso trumpet player would be a great asset in approaching electroacoustic control. Virtuosity

in free improvisation was defined as the speed at which it was possible to react to other players actions and also in the ability to take initiative.

In free improvisations with other players the electrumpet operated reasonably well and commentary from acoustic peers suggested that the instrument was growing towards adulthood. The Margareth Guthman competition win and comments afterwards in 2013 also seemed to suggest that the Electrumpet was on its way to become a full-grown instrument. Acoustic virtuosity played an important role in the result of that competition though and giving a limited performance of five minutes to show off is very different from playing a concert. An example of the instrument in concert during the PhD but before the implementation of the new system can be found in the appendix (Appendix G.5.4.2):

The Instrument Room [#7] Dianne/Bernhard/Hans improv

The instrument works quite well in this context since the movement in the whole trio stays slow.

The limited virtuoso repertoire of the instrument was an issue and the development of the harmoniser was actually a setback in virtuosity. When there was only a limited amount of effects it was relatively easy to reach them, but it became increasingly complex with the growing number of possibilities.

Combining the harmoniser with other effects was also an issue. To suddenly emerge with full blown chords after a section with the much subtler sound manipulations already present on the instrument was a musical challenge. The sound of the harmonisation was also too heavy since a lot of the sound luthier knowledge needed to clear the output sound was not implemented yet.

In an improvisational performance with other players it is relatively easy to step out of the loop, leisurely prepare for the next action, and come in with a 'new instrument' some time later, while staying engaged with the actions of others. This could be called a mixing approach to improvisation. An appreciation was developed towards a morphing approach though and within the old system that was very complicated. Too much time was needed to go from one setting to the next losing engagement while being occupied with implementing the transition and playing at the same time.

The interviews provided insight here. Some interview participants had patches that were pieces. A patch is a program written in a sound programming environment like MAX, Supercollider, Ableton, Chuck or the also programmable hardware environment provided by the Kyma System. Within that patch a limited number of effects are assembled and can be controlled using a set of predetermined parameters and parameter mapping. For each new piece these participants made, they also build a new patch.

Coming from that same approach, Sam Pluta (Appendix A.1) decided to create one system since reusing code from old pieces, which happened a lot, was more of a hassle than incorporating all pieces in just one system. In his system, he has incorporated all his existing pieces into one instrument with a fixed mapping to

his controls. More importantly, he devised an interaction method to be able to quickly change effect routings and parameter control.

Not only his interview provided insights, but improvising together using the Electrumpet made the effectiveness of Pluta's instrument and playing clear as well. His speed and his ability to change sounds were a completely new experience of electroacoustic virtuosity and not easily matched with the slow-going but sound wise dominant changes in Electrumpet processing. Especially confronting were the lighter sounds on his instrument, apart from playing light on the trumpet itself, not enough possibilities were there to match. Unfortunately, the zoom recording of our session together could not be mixed properly.

Duo Sam Pluta / Hans Leeuw, Huddersfield, November 24, 2016

Experiencing Pluta's virtuosity and the inability to challenge it properly, the expectation was to find some form of instrumental virtuosity behind it; there wasn't. According to Pluta, instrumental growth happened mainly on stage and during rehearsal and especially when meeting new musicians with a different approach (Appendix A.1). This difference in instrumental practise culture within the realm of electronic music is also observed in students of Music Technology at the University of the Arts Utrecht. There is no methodology and it is just doing. Tim Excile (Appendix A.6) phrased it as follows: 'That is not necessarily about practising really hard for six hours a day for a year or however you want to practise. It is it its…Well its basically it's about you need time in front of an audience.'

Incorporating a similar system to that of Pluta on the Electrumpet became the new challenge. The problem though was that the number of knobs and the matrix like operation he used could never fit on a trumpet let alone that it would be possible to access them all while playing. For a while it seemed that that kind of virtuosity was just not for the Electrumpet. That was until the break through that is described in chapter 6 and referenced in other parts of this chapter. The system is far from the same as that of Sam Pluta, but it takes some essential elements needed for virtuosity in an electroacoustic setting into account.

5.4.3 Improvisation, the current state of the instrument and reflection

Does the new Electrumpet system and instrumental upgrades now make the instrument perfect for virtuoso electroacoustic improvisation? A new session with Sam Pluta would be informative to determine that, but a session with Diemo Schwarz at IRCAM (Appendix G5.4.3a) already shows a faster pace of the Electrumpet in the improvisation. Most noteworthy though is that the harmoniser can be used more freely because of the arpeggiator implementation. At the time of this recording the new system was just finished:

Diemo Schwarz and Hans Leeuw, live recording at IRCAM, April 28, 2018

Another recording around that time with the micro tonal Fokker organ showed that it was quite easy with the new system to tinker MIDI control into the system

and construct a 31-tone harmonization (Appendix G5.4.3b). Time to work with the organ was limited:

Swarm – Hans Leeuw recorded at the 'Muziekgebouw aan het IJ', May 13, 2018

There are a number of indicators that would say that there is improvement in the new system, even while the physical control of the instrument can still be improved upon:

- Every sound processing and control situation on the instrument can be reached playing at most four phrases with the in-between stages still viable to continue playing. (see movie example in 5.3.1.3)
- Playing with the eyes closed and still knowing the current state of the instrument is quite possible (see 5.2.2.3). Especially since most states of the instrument are combinations of single modules which can all be inserted and exchanged separately. So when in doubt about a certain module being active or in a certain state a single phrase can ensure the required mode. An intuitive connection with the instrument will help the focus on the music itself. Of course, this connects to the instrumentalist and performance persona as well.
- New modules won't increase the complexity of the system per sé. The number of phrases needed for a change will remain the same although the total number of phrases that mean something will increase so the challenge for the memory will indeed increase as well. It is more like learning a larger repertoire by heart.
- Inspired by Pluta there is also a multidimensional grid of operation. The octavation option for example stays active when moving to another sound environment in which it is implemented as well. This ensures that pitch transitions are not sudden if they are not supposed to be and maybe even more important, the improviser stays aware of the movement and the position in the multidimensional sound grid. Octavation exists in all environments. This multidimensional thinking is now an integral part in the thinking about further expansion of the system. It is shown below in a 3-dimensional representation but the number of dimensions is not limited that way.

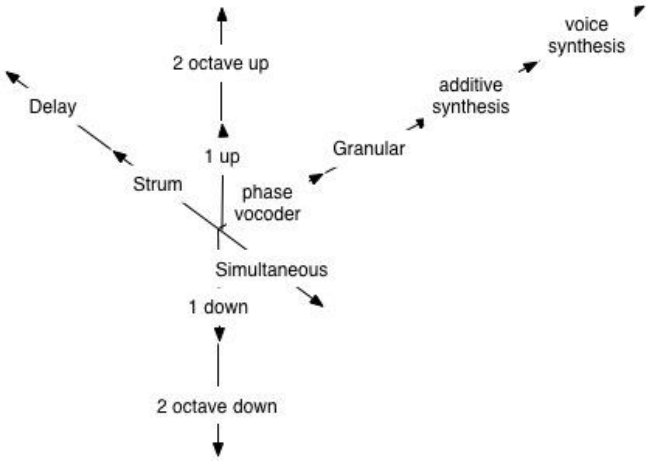


Figure 5.4.3 1

This 'change one parameter at a time' paradigm in a complex musical environment is also a technique used in the tradition of Carnatic music. The technique of Gati Bhedam for example (Reina, 2015, Chapter 4) typically keeps phrase lengths (Jathi) the same when there is a change in speed or speeds (Gati) the same when there is a change in phrase lengths; thus, keeping coherence between before and after the change for both the improviser and the listener.

These improvements are important markers to improve the opportunities for improvisation on the Electrumpet. There are fields that are still underdeveloped though.

- All the organisation of notes is done within the harmoniser and although there are added features like octavation, stretching, arpeggiating in different orders, strumming, crescendi and decrescendo on arpeggio's, automated parameter change, and most important different ways of tonal organisation then the harmoniser is traditionally known for (see 5.3.1.4) the basic organisation is still the harmoniser. Of course, the idea to bring the harmoniser in the field of sound processing and making it less static and much more versatile was one of the goals that emerged during the PhD period. There are other ways to organise the sound material that is in the buffer though. these are lightly touched upon but the idea of multidimensionality should be implemented somehow in these new additions as well. Some ideas will be discussed in the future work section.
- With the implementation of the valve system and before that the attention to the development of the harmoniser the use of the continuous sensors got much less attention. These were the infrared sensor and the pressure sensors on the third valve that were considered most important for expression before the start of the PhD. Their effectiveness in manipulating sound while the Electrumpet setting is in a virtual node as seen in figure 5.4.3 1 has not been explored as thoroughly as wished for yet. The new much more responsive sensors are much more suitable for this kind of interaction then the old sensors though.

Looking back to the context of the band Tetzepi (5.4.1) there are a number of issues using the old instrument that are solved using the new system.

Operating within model rhythmical pieces would be possible without noticeable latency. Also, the current sound has more 'impact' and can be enhanced using the transposition / ring modulator combination.

This includes the use of the Electrumpet's harmoniser. Quick successions of chords are still difficult to learn, but modal pieces with a slower harmonic development are especially suitable for interactive use. The possibility to link delay times to the current tempo through timed use of the digital valves added new opportunities.

5.5 Electrumpet design from the tinkerer persona perspective

The tinkerer persona is very important as it relates to the Electrumpet. The tinkerer has a certain tension with the designer and composer personas if we

define the latter two closely to the conceptual level that they occupy in the model. In a tinkering iterative approach, new opportunities for sound manipulation and mapping control are tried out within the existing system and when successful adapted into it. The composer and designer personas plan more ahead. There can be a healthy interchange between the tinkerer and those personas though when tinkering leads to discoveries that can be worked out by one of the other personas or when tinkering leads to too much chaos and needs to be reined in.

When not working on fundamental redesign, a lot of time is spent on tinkering. Some of that tinkering is mending loose ends. Much though has to do with making it sound just a little bit better, choose some different presets, try out some new modules and gradually expand the system and its possibilities. This is true both for the old and the new system. What changed Is the effectiveness of tinkering. Adding changes in the old system was slowly grinding to a halt, while complexity and time spent rose and frustration built.

Tinkering suggests that it is frivolous and leads to nothing fundamental, another word to describe it is 'serious play' though and literature suggests that it is a very effective and motivating way of learning (Rieber, 2001, p. 2). While learning is not the goal of building the Electrumpet, all the experimentation on new additions does build the expertise in building an Electrumpet. Also, it is probably the pleasure derived from tinkering that motivates the improvement of the instrument after more than 10 years of marginally funded work.

An example of a sound processing system that lends itself explicitly for tinkering is Ableton (Ableton, 2001). Ready-made modules can easily be interchanged in an environment that allows for simple routing opportunities and takes care of fluent mixing. A satisfactory preset can be stored as a scene and scenes can easily be called forward in a multi voice environment. There is even the opportunity to make custom modules using MAX or to use the modules of others.

Why not use Ableton? The inception of the Electrumpet was several years before the opportunity to mix MAX and Ableton and sticking with the toolbox is one of the reasons. Looking at the current system though, using Ableton would not have made the system simpler and would also have created extra overhead. Creating custom sound and control has also become part of the creative process. The conviction is that it ultimately increases quality and even more important identity. Think of the per voice high pass filtering coupled with pitch recognition described in 5.3.1.1.

5.5.1 The suitability for tinkering of the original Electrumpet system

Tinkering can be done on both the software and the hardware parts of the instrument. Although there has been some tinkering in hardware for the Electrumpet almost all activities in hardware and physical manufacturing were part of a redesign of the instrument. We will focus here on the tinkering within the software system.

The original 'design' of the Electrumpet system was originally limited by CPU availability on the computer. A freeze patch based on additive resynthesis of the

trumpet patch could maximally be run four times simultaneously so four separate audio channels would basically run through the patch with different forms of audio processing along the way. These channels were conveniently related to the physical layout of the instrument. Each channel had a corresponding knob for controlling record and play and the four so-called digital valves could basically be used for scrolling through the recorded buffers or to make certain selections within those buffers. These knobs and valves were conveniently aligned with the normal Electrumpet valves so they were easily accessible.

The essence of the system was controlling those channels individually. Each channel could take an alternative path through the patch using other forms of processing or passing them by. Adding new opportunities meant adding new paths and switches to turn those paths on and off. A computer upgrade in 2011 did not lead to a fundamental redesign since more power was available. The system had become complex and redesign would cost time. In hindsight this was probably a mistake.

The channel layout and the way in which it was controlled made tinkering attempts complicated and frustrating. Inserting a new interactive or sound processing possibility almost always meant adding a new switch configuration for the buttons on the Electrumpet and often had implications for the channel in other parts of its path. You can think of adapting the volume, filtering, EQ or similar before or after the insertion. Even worse were additions that involved switching channels on and off. Think of changing from a two voiced to a four voiced harmonisation while one of the channels was still recording and playing material. It made the patch increasingly complicated and hard to decipher in case of issues. Each addition also made another addition more complicated so it could become a choice issue to either forget about the addition or to skip the old one.

5.5.2 Changes that influenced the suitability for tinkering in the new Electrumpet system

Even though tinkering led to a complicated system, the value of the tinkerer persona was acknowledged when designing the new Electrumpet. That persona should be able to playfully and creatively create new musical and sound material and new interactions for the instrument in a reasonably quick manner.

While the tinkerer persona in itself may not care for organisation it does benefit from an organised environment where everything can be found where it is expected to be. Modules should each have their own specified task and the general setup should be clear and simple. In the new system this was implemented by using a clear sound flow principle:

1. Input, recording/buffering, sound analysis and sound adjustment (1 channel)
2. Sound processing modules mostly based on some form of resynthesis (Parallel, max 12 channels)
3. Sound processing modules directly following step 2 (Parallel, max 12 channels) using control information from step 2.
4. Sound ‘post processing’ and spatialization

The 12 modules in steps 2 and 3 can take different forms.

Control over this system is done through the Model, View Controller principle (Lossius et al., 2014).

Adding a new sound processing idea can be quite quick. Within a few hours a new modalys physical modelling idea in step 3 following harmonisation in step 2 could be implemented and it worked. It then took some time to further perfect it, but that whole process is now isolated from the rest of the system making it comparable to the effort of working on a separate patch only dedicated to physical modelling.

That the whole functionality of the rest of the patch stays in tact means that it is also easy to test with different settings in other parts of the patch thus testing the multidimensionality aspect discussed in 5.4.3.

5.5.3 Tinkering, the current state of the instrument and reflection

Is the Electrumpet system now perfect for tinkering? The last paragraph would suggest that the answer is definitely yes and the improvement for this persona might be one of the clearest. It is true that especially the sound modules are now clearly defined and easy to embellish.

We did not explicitly discuss the control modules in the last paragraph. Adding complexity and new features in control is a magnitude bigger than it used to be. It becomes clear though that the control modules are moving into a similar complexity direction as originally the whole patch, so it might be that a fundamental approach may prove more viable than to keep tinkering.

Looking back at the process of the redesign from the tinkerer persona in particular, it is now easy to say that it should have happened much earlier. Although it is hard to reconstruct an exact record of all the changes in the system before the big system overhaul, it is safe to say that the current system is much more stable and mostly changes through addition and not so much through redesign of the redesign.

There is always the question whether it is better to continue tinkering or that a redesign is warranted. Mostly a redesign pays itself back but it takes discipline to make the decision. The tuning of the harmonisation tab has been recently redesigned for example and it was again too late. Days to weeks spent on a system with an unclear GUI or complex programmatic interaction costs much more time in the end than a fundamental redesign that will also open up insight in what is actually going on and is much more pleasurable to work with.

Not always is redesign possible immediately. There has to be a good idea for the redesign and before that good idea is conceived complexity may increase creeping but steadily. A deliberate effort may be necessary to let the design persona take over. It will probably mean some stagnation in acquiring new possibilities but at the other hand the speed can increase after the intervention and newly conceived modules can profit from the same design principles.

An advice to other instrument designers might be to keep track of tinkering. If a certain task is often repeated or if a certain part in your system is subject to continuous tinkering then it is time for a redesign; even more so when clarity is important in that task. It will almost always be more efficient than continued tinkering.

5.6 Electrumpet design from the composer persona perspective

As with every persona the composer persona was partly formed through past experiences. In this case the combination of composition with live-electronics. The first experiences, mostly fixed pieces, with live electronics were not especially exciting. That changed hearing Edwin van der Heide during a Gaudeamus concert in the Netherlands in 1999. Edwin van der Heide was part of the Sensorband and played an instrument called the MIDI-Conductor (Bongers, 1998, pp. 16–17).

The instrument that van der Heide developed could be used to time stretch and transpose samples using granular synthesis in a live performance. A collaboration between van der Heide and Tetzepi (5.4) was setup in 2000 for Dutch radio and a few pieces of that program were later recorded on CD. One of the pieces, written by the author, was a guided improvisation, a dialogue between van der Heide and the sections of Tetzepi, Matrix:

Matrix – Hans Leeuw, recorded 2001 on the CD 'Shu' by Tetzepi.

It should be noted that the functionality of the instrument is part of the piece as well. Positively inspired by van der Heide and negatively by some others, starting with the functionality and interactivity of the instrument was the basis for the Electrumpet from the start of its development in 2008.

5.6.1 Composition at the start of the PhD

It is hard to describe the exact aim for composition at the start of the PhD. The Electrumpet was in the first place an instrument but it was always clear that composition skills and ideas were part of designing the instrument. New interactions, sounds and sound organisation were always conceived with a sounding result, also in time, in mind.

In a classical view of composition is the construction of a piece that then in turn is performed by an instrumentalist. That approach was never dismissed in the case of the Electrumpet but it turned out that adapting that approach was less opportune for the development needed in the instrument.

The system with all its knobs and sensors was too complex and too fragile for more elaborate compositions. A more complex composition using the Electrumpet involving a dedicated timeline for example, would have actually meant a new system with all its trouble shouting hazards. It would also mean not improving the improvisation setup which was always the main focus.

Another slowing factor at the time was the recent invention of the interactive harmoniser. It was at the same time a device with lots of possibilities, and a big break with the way in which the Electrumpet was used up to then.

5.6.2 The evolution to "composing from the instrument"

During the first period working with the harmoniser, there was an evolution through exploration in the possibilities of the device. Small improvised pieces were made and performed on low key venues. The harmonisations were simple and related to a more traditional musical context then the one discussed in paragraph 5.4.

The composer persona deliberately chose this approach. Pieces follow from the process resulting in ever increasing complexity. Ideas arise from tinkering and are explored for opportunities. Further exploration of good ideas leads to new opportunities and gradually a personal artistic implementation grows that integrates the composer persona with all the other personas involved in creating the instrument.

The interactive harmoniser originated from the idea to use a delay line for a low latency well sounding octaver. This led to other fixed transpositions and subsequently harmonisation. Using pitch recognition to define chords per note was the next step that was quickly followed by the idea to organise harmonisations into chord sets. In order to check its effectiveness and sound the first harmonisations were with three voices lower than the trumpet itself emulating jazz harmonisations from the sixties.

The newly implemented ideas were exiting. It sounded good compared to commercially available harmonisers, and with the use of onset, pitch detection and interaction through the ribbon controller, this was a unique way of harmonising a horn sound even while there was no artistic novelty yet. The delay line method did not permit upward transposition but that could be added with reasonably low latency using the phase vocoder. A particular interesting interaction was now available. Contrapuntal interactive movement of voices:

Demonstrating contrapuntal movement in the two GUI interfaces.

From the perspective of sounding material still not very inventive, but from the perspective of interaction a breakthrough in interactive harmonisation. This does not sound like a typical harmoniser anymore.

Could this contrapuntal idea be implemented with more complex chords as well? Not with a particular piece in mind but more in the general direction of modal composition / pieces. This harmonisation was supposed to have a certain personal flavour but would also incorporate the idea of counterpoint. This turned out to be complex. The best playable result thus far is to keep the inner voices together with the trumpet as the top voice of these inner voices and the outer voices moving in counterpoint. The Electrumpet has a particular instrumentation challenge as well.

After this exercise, other forms of harmonisation that veered of the particular path of Jazz improvisation were constructed as well to explore their usefulness in free improvisation. This inspired the idea to start calling this 'composing from the instrument'.

With a limit of three voices transposed upwards (phase vocoder) and six downwards (the delay line approach was computational inexpensive) this was where composition ended as far as the old Electrumpet system version was concerned.

5.6.3 'Composing from the instrument' and the new version

After the upgrade of the system, instead of continuing to develop new harmonisations, it was deemed more interesting to develop new interactions with the existing harmonisations, thus opening up new opportunities for improvisation. Instead of only using the harmoniser in a vertical manner, meaning all notes in the harmonisation starting at the same time, it could now be used in an arpeggiated way.

Apart from the obvious organisation in note order (up down, down up, diverge, converge etcetera) other musical and/or sound parameters can now be organised in a timed order as well. A simple addition to transpose the whole harmonisation with octaves, impossible in the old rigid system was another sudden expansion. What was first a harmoniser with some extra features, now became a vehicle to compose short phrases that could be controlled in the context of a live improvisation.

In exploring etudes for the Electrumpet but also for educational purposes TSU's were investigated (Hautbois, 1991). TSU is a means to describe small fragments of music based on their "associative denomination". TSU's were deemed particularly interesting in the context of improvisation as it is not only the sound fragment itself that is in play but also the impact of that particular sound fragment on another player participating in the improvisation and his or her possible response to it.

The team of researchers at the Laboratoire Musique et Informatique de Marseille identified 19 different TSU's listening to contemporary electroacoustic music in particular. Though TSU's are a means of description in the first place in the context of Electrumpet repertoire they can also be used as a means of scrutinizing the repertoire and even designing it. The current effort in designing Electrumpet repertoire is the combination of TSU like gestures with the harmoniser delay function. These efforts have been mostly tinkered in search for a more permanent designed solution in the control module. (see example in 5.1.1.3)

These composed TSU gestures come close to some of the expressive gestures that were part of the original Electrumpet repertoire. A new goal has come into reach considering the multidimensionality expressed in 5.4.3 where the one-dimensional expressive play can morph into TSU gestures in the harmoniser.

5.6.4 Reflection on the composer persona.

During the PhD, the composer persona has been redefined in relation to Electrumpet design. The process was in particular complex since the starting point was musically schizophrenic with on the one hand a practice context utilising in particular free improvisation, explored within the professional

context of the band Tetzepi in the years before the PhD, and on the other hand the recent invention of a promising interactive harmoniser that was technically and artistically in its infancy.

Too much time has been spend sticking with a system that was somewhat suitable for the old situation but inadequate for the new situation. Looking back, the redesign should have been much earlier, which would have facilitated the process of 'composing from the instrument' instead of searching for a way to 'compose for the instrument' with a flawed and artistically unclear system.

Ditching the harmoniser all together could have been a viable choice in line with the artistic practice at the time. That might have led to more work in the sense of concerts in line with the artistic practice up to then, but fundamental progress would probably not have happened. Forcing the solution of the harmoniser issue has led to other inventions.

5.7 Electrumpet design from the designer persona perspective

The designer persona can be seen in relation to the blue hat in the description of the six thinking hats (De Bono, 2017, pp. 146–172). The blue hat shapes the process. This similar to part of the function that the designer persona has in its directional function in relation to the other personas. That can be in relation to the attention that is given to each of the other personas but it can also be in relation to the performance of one of the other personas.

The position of this persona in relation to Electrumpet design starts with the will to observe musical instrument design from this position knowing that a few of the other personas are much longer and deeper developed. The will to spend serious time on all personas in the model is also a defining characteristic. Further, there should be an open mind toward the integration of knowledge from other scientific or professional fields that could potentially improve the design. 'Out of the box thinking' a term often used within design should always be part of the process.

Different instrument designers have different priorities. The Electrumpet was upgraded with all personas more or less given equal attention, but the improviser persona clearly had a leading role in forcing the upgrade. The integration of the personas is felt as an advantage

The Electrumpet is a hyper instrument. From the start of its design the ultimate goal was to design an instrument where the physical and digital control would blend preferably in such a way that they would be inseparably from each other from the experience of the player in flow state. It was named 'true hybrid play'.

5.7.1 Starting position of the designer persona in relation to the Electrumpet

The focus on 'true hybrid play' was partially derived from the emphasis on embodiment within the NIME community at the time (NIME reader?). The 'E' in NIME (Dobrian & Kop, 2006) article referenced earlier in this thesis affirmed the importance of instrumental virtuoso in the instrumental design process.

In private conversations within and outside the NIME community the notion of virtuoso musicians having an innate ability to 'understand' music on a different level and thus potentially be better designers of new musical instruments was also a determining mind set.

If we compare with paragraph 5.1 we see that the designer persona and the instrumentalist persona were very connected at the start of the PhD. Of course there were no personas defined at the start of the PhD yet.

Some other design principles next to 'true hybrid play' relevant to the Electrumpet that have not significantly changed should be mentioned as well:

- The Electrumpet is not supposed to be a synthesizer but will always involve some kind of translation of the acoustic trumpet sound input.
- The Electrumpet is an instrument and not a collection of instruments.

5.7.2 Evolution of the designer persona

A shared value set amongst professional performers was hypothesized. Such a shared value set could be beneficial to instrument design. Could it be possible to capture professional performer insight in such a way that it would benefit instrument design? It was decided to seek further information on ideal embodiment from peer professional performers who designed their own electroacoustic instrument.

The interviews did only partially deliver such a professional performer insight though. The shared part of the insights was mainly concentrated around the performer aspects of their work. The transfer of performer insights to non-performer aspects was often of a practical nature, these insights can be seen in the influence of the performer and sometimes instrumentalist persona on luthier aspects.

These insights are often aligned with comparable research into instrument design (Cook, 2009b).

More interesting in the interviews for the design of the Electrumpet were the ideas of composition and improvisation in relation to instrument design. The interest here though was more in the differences in insights than in the similarities.

The idea of describing ideal performer values, apart from practical considerations, changed to facilitating methodology for the implementation of a personal vision on instrument design. A design guided by artistic, performative and instrumental personal values connected to improvisation and composition.

This resulted in the persona model. Evaluating the Electrumpet with the model in mind confirmed that the personal requirements connected to the improviser persona were not met in the then existing Electrumpet design. That halted the development for a while, as moving forward as usual was considered futile; it was unclear if the impasse could be broken. Eventually though it led to a breakthrough that combined the input from the improviser persona and the out of the box thinking of the designer persona.

Important in that breakthrough was where the focus of the designer persona was at the time. Sam Pluta's PhD thesis has been very instrumental. The solution offered in that thesis glued with the personal idea of what an instrument should be able to do in an improvisational context. The only problem with that solution was that it was not one on one transferable to the Electrumpet. The requirement to find a smart integration for the harmoniser also hampered the development. It had narrowed the search field though. Also notable is that the inspiration for the final breakthrough was based on the notion of a neurological theory (see 6.5).

Finally, the new Electrumpet uses the learned embodiment of the original acoustic trumpet and we are back at the embodiment theme important within the NIME community. The route to get there though was not through an investigation into embodiment itself but it was the result of a search into a way to virtuously navigate the multidimensional, often discrete, space of electroacoustic improvisation. The harmoniser being a hinderance at first was in the end instrumental in finding a logical coding scheme.

5.7.3 Persona model and redesign

The persona model in itself is a manifestation of the activities of the designer persona. The designer persona can use it as a tool for more efficient or more thorough (re)design of electroacoustic instruments.

One of the ways in which the designer persona utilized the model in the redesign is in acknowledging the different personas. Ideally the system should afford for all the personas to function optimally while using the Electrumpet system.

5.7.4 Reflection on the designer persona

In hindsight the designer persona has not been involved enough in the past. During the inception of the instrument around 2008 it was active but it has been dormant for quite a while, even during the hardware redesign in 2012. That redesign was purely based on sturdiness or actually practical issues from the performer persona perspective; 'out of the box thinking' was absent for a long time.

True, new scenarios were invented and added to the Electrumpet repertoire and new electronic hardware technology was experimented with. It was called iterative design at that moment but in fact it was mostly iterative tinkering. There is still iterative tinkering but there is now a process on top of it that warrants redesign if extra tinkering becomes to muddied and threatens the clarity of the whole system.

Redesign has become comparatively easy since the system utilizes a modular setup following the Model View Controller paradigm (Lossius et al., 2014) in an adapted version. There is a separation in sound and note organisation that is at the same time flexible enough to merge the two aspects.

The redesign was especially aimed at the improviser persona, since it was the tension between the improviser persona and the old system that forced the issue. Currently though, especially the tinkerer persona benefits followed closely by the improviser and the composer personas. To a lesser extent the

instrumentalist and performer personas benefit but longer experience with the improved instrument is needed to really determine that. The luthier persona is more complex. Considering the artisan luthier and electronic hardware luthier sub personas, there are a lot of improvements. They are for the most part improvements that could have happened regardless the system redesign. These improvements still resonate with the persona model though. The 'sound luthier' (5.3.1) benefits greatly from the overview and modularity that the new system provides.

5.8 Reflection on the use of the persona model

In this paragraph the effectiveness of the persona model itself in relation to Electrumpet design is discussed.

Separation in performer and instrumentalist persona:

The performer and instrumentalist persona in the model are separated from each other. It is important that this distinction is made based on the interviews with professional performers making their own instruments. It is a practical separation aimed at addressing specific issues during the design process choosing a different perspective.

That separation is not visible in other literature. In both key articles that deal with instrumentality (Hardjowirogo, 2016) and embodiment as in extension of the body (Nijs et al., 2009), these aspects are treated as an integral part of instrumentality. Nijs though, puts the distinction in the description of the musical instrument as "functional organ":

"On the one hand the musician influences the musical instrument (instrumentalization). According to his needs he will attribute specific functions to the instrument. Moreover, a musician always seeks to perfect his instrument by making material adaptations (e.g. by choosing strings, reeds, ligatures). On the other hand, the musical instrument has an impact on the musician (instrumentation) through the cognitive structuring of his involvement during performance." (Nijs et al., 2009, p. 136)

The performer persona has shaped the solution for a number of practical issues in the Electrumpet. Its potential though is in the thorough analysis of the storytelling aspect of the instrument while on stage. This should be the next reflective phase in designing and composing Electrumpet repertoire.

Composer persona: Composing from the instrument

The notion of composing from the instrument as opposed to composing for the instrument is a position that gives focus on the further development of the instrument that feels right. It determines the attitude with which the creative process gets its form and it glues with the tinkerer and improviser personas. Furthermore, the real creativity and the main contribution of the Electrumpet to the discourse comes from the inventiveness of its compositional interaction with sound material in real time.

Defining such a very personal position for oneself helps to focus the design process and is the strength of the persona model. Definitions of such positions for all the personas together with an indication of importance, shows from which angle a discussion on instrument design is approached.

Tinkerer persona:

Making the tinkerer a separate persona instead of part of the designer persona has been a good decision. Not only has the tinkerer role been emancipated, but it has also revealed the tension between the designer and tinkerer personas in the iterative design process of the Electrumpet. The importance of the tinkerer persona as a motivational way of working has been established but it has also become clear that tinkering which is essentially unstructured should happen in a structured environment and should always be in communication with the designer persona.

Luthier persona:

Subdividing the luthier persona in three separate sub personas became inevitable while analysing the activities within this persona. It is not only the activities but also the positions taken for each of the sub personas that are mostly independent from each other; the aesthetic considerations for the artisan luthier on material and shape do not have to line up with a particular position on sound clarity from the sound luthier.

Improviser persona:

This persona was the most important persona during the PhD period because of its influence on the redesign. It resulted in a complex discreet mapping system aimed at virtuosity that is truly unique for hyper instruments. It was putting things sharp through the development of the persona model and the interview and musical confrontations with Sam Pluta that resulted in a stagnation from which this system arose as a solution.

Analyzing the redesign of the Electrumpet was just one effort to verify the persona model. There is confidence that the model would work similarly for comparable instruments. Within the NIME community though, not everybody concurs with the sort of separation between personas that is suggested in the model and it is even argued that it leads to an underdeveloped conceptual practice (Gurevich & Treviño, 2007):

> 'Two of the most prominent stated or implied goals of NIME are 1) to "place … this music in the great trajectory of Western European art music composition" by using computers to create new sounds, but to leave the text/act paradigm intact such that the computers are at best transparent, at worst appear as musical instruments; and 2) to make the performance of music with electronics 'easy', 'palatable', and 'transparent' for the audience.

Although this is stated provocatively, there is certainly truth to it. The Electrumpet is an instrument that stays relatively close to the text/act paradigm and it is fair to say that it is probably only valid within that context and it does not try to break 'NIME's stated or implied goals.'

Chapter 6, implementation of new insights in instrument design.

In this chapter the new Electrumpet system is introduced. This new system has been implemented relatively late into the PhD process. It implements a few core findings from the conducted research and is the result of a needed breakthrough enabling the implementation of these findings.

6.1 What is the Essence of the new System?

The core improvements:

1. In the new system the player is able to quickly switch between different ways of audio processing.
2. Different ways of processing are much more independent from each other:
    a. This makes the implementation of changes much easier and thus satisfies the tinkerer persona.
    b. This makes it much easier to add new modules and ideas.
3. The new system affords to use some of the embodied skills of the trumpet player.
4. The new system implements the musical virtuosity of a trumpet player.
5. The new system implements the musical memory of a particular musician.
6. The new system implements a hierarchical organisation of the interaction with nested mappings. This expands the number of possibilities without becoming too complex.
7. The most stable sensors are now fully implemented in favour of some less trustworthy ones.
8. The new system is easier and more logical to learn. The learned skills are sustainable although careful planning with an eye on the future is needed when implementing controls with a lot of opportunities.
9. All of the above makes the instrument more trustworthy in its use.

6.2 Implementing virtuosity as core motif:

One of the concepts that developed while analysing the interviews was the notion of virtuosity and the way it was differently interpreted by the different interview participants. People with a traditional instrumental background were more inclined to mention the embodied aspect of virtuosity, the fine control, being in the moment while Pluta and de Vreede mentioned a kind of virtuosity that deals much more with making the right choice at the right moment. The way de Vreede interprets it is very similar to the ‘second order virtuosity’ mentioned by Hildebrand (Hildebrand et al., 2016, p. 348): ‘A Second Order Virtuoso is an artist of exceptional skills with regard to technical and mental ability to create, observe, and shape time-based art works’. But Pluta in particular mentions the ability to quickly change and make choices.

Thinking about virtuosity in this new subdivided manner opened up the mind to think about the way in which the instrument afforded for the different kinds of virtuosity. In the end this resulted in a breakthrough that solved the 'choice virtuosity' problem on the Electrumpet once and for all and it was inspired by watching a documentary.

6.3 The phrase idea: implementing virtuosity on the Electrumpet.

Neuroscientist professor David Eagleman's in his documentary-series 'The Brain' recited Libet's experiments on conscious awareness of events (Libet, 1973). The brain takes about 0.5s to become consciously aware of an event as for example clapping your own hands. There was this awareness that in that same time four or five trumpet notes could be played before becoming aware of the first. This in turn triggered the notion that this is already a phrase. For a virtuoso musician playing a phrase is an event in itself, just as quick as any other single action and costing little effort.

This notion was a real Eureka moment when it happened. The consequence is that a system using the same fundamental information science approach as the system implemented by Pluta could also be implemented on the existing Electrumpet.

There were already digital valves on the instrument on the verge of being discarded. These digital valves share the same feel and dimensions as the normal trumpet valves thus a phrase played on the normal trumpet can easily be played on the digital valves. If we ignore the lips also used on the trumpet, there are seven positions for a single note on the digital valves and the player can easily imagine virtual notes when depressing those valves.

The player always has to start from and return to an open position (no valves depressed) for the system to recognize that a phrase was played. With phrase lengths from 1 up till 7 that is hundreds of thousands of possibilities. And in fact each of those phrases is the equivalence of pushing a single button or even a group of buttons on a digital control surface.

No electronic musical instrument has so many knobs but we still have to map these phrases into something meaningful for the player.

6.4 The organisation of the phrases:

After considering a few other options a second breakthrough moment helped organizing the phrase system.

6.4.1 Associative organisation:

Since only a couple of hundreds of phrases are needed to control the instrument in such an abundance of possible phrases, the phrases for control can be chosen rather indiscriminately because we don't have to worry too much about picking the same phrase twice.

The same phrase can be used more often as well for different controls if that phrase is nested under another phrase. Now we can construct similarities between phrases that control different things.

In the next example (figure 5) a phrase is played on the digital valves followed by a second one. In the first example we first trigger that we go to harmonisation mode and then the harmonisation is arpeggiated downward. In the second example we choose the sound module 'Spectral Delay', sound modules and the control of them is always done with the 4th valve down. The same phrase, with the 4th valve added, as in the first example now results in a downward shift.

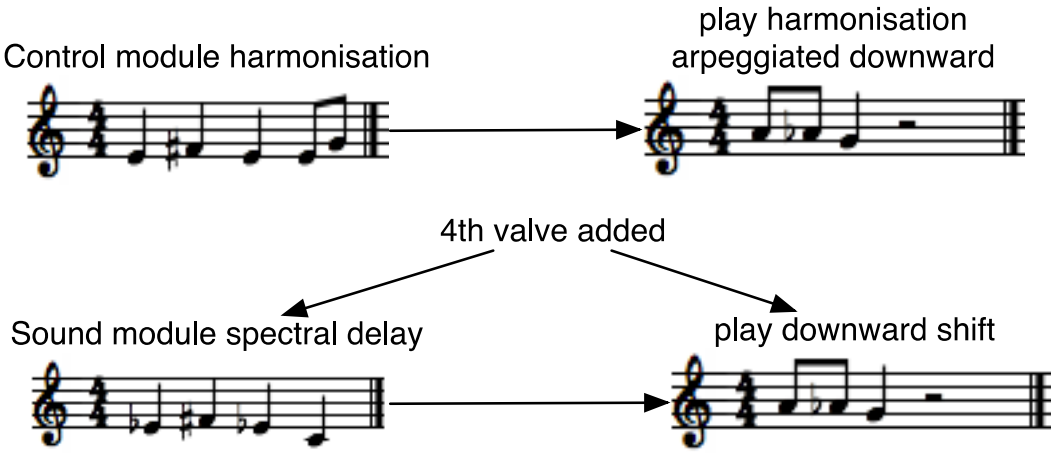


Figure 22 Same phrase, different but similar control.

At the moment phrases are chosen based on their associative meaning. There is a difference between longer and shorter phrases. A shorter phrase is used in general for those actions requiring more speed.

The interactive harmoniser module will be inspected further:

6.4.2 Interactive harmoniser model control:

The first step is to choose the right controller surface. At this moment there are three different control surfaces: the harmoniser, a serial module (with different implementations) and an overtone module (to be used specifically with the spectral delay. Choosing the control surface goes as follows:

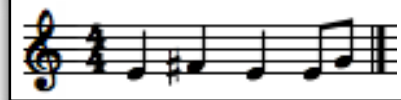
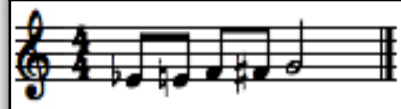
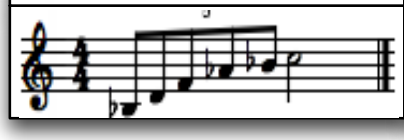
Phrase	Module name
	*Harmoniser*
	*Serialize*
	*OvertoneDelay*

Figure 23 Control Module choice phrases

In the software GUI this subsection will pop up. The subsection is a bpatcher in the MAX programming language.

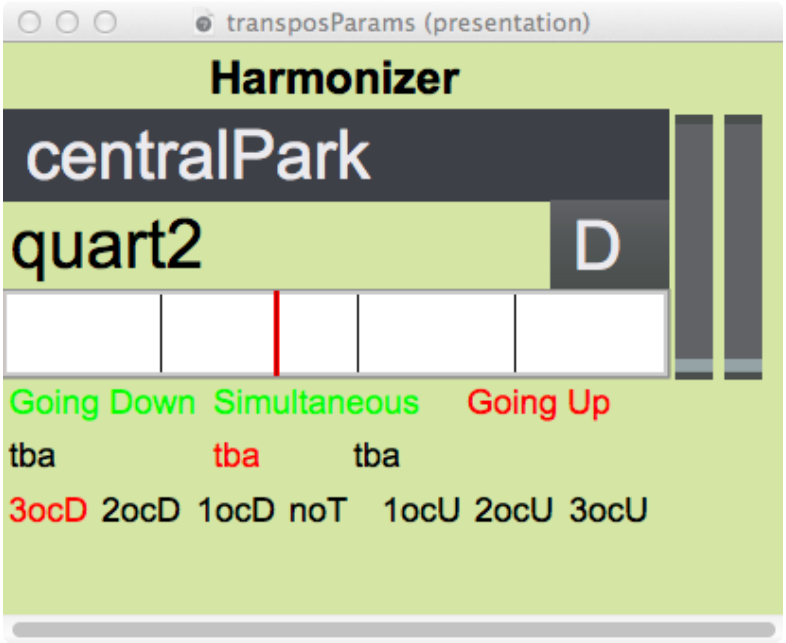


Figure 24 Harmonizer bpatcher

The harmonizer module is now active. The red line on the white background represents the position of the thumb on the ribbon controller. At the moment the thumb is in the second position which corresponds with harmonisation family ‘quart2’, a harmonisation in quarters.

Playing a phrase we can choose another harmonisation.

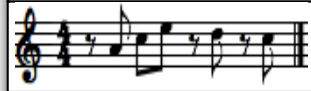
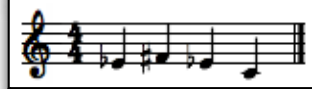
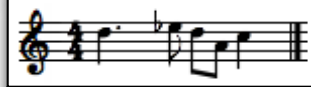
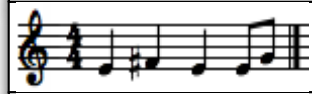
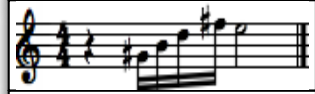
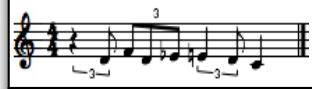
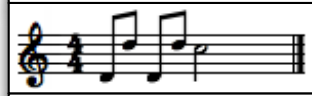
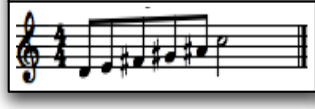
Only 'normal' 3 valves ↓ Phrase	Harmonisation	SubDivision
	*Stolen Moments*	
	*Central Park in the Dark*	
	*Caravan*	
	*Lonely Woman / Own song*	
	*Joy Spring*	*section A, A', B*
	*Nancy*	*section A, A', B*
	*Octaves*	
	*Fundamental*	

Figure 25 Song harmonisation sets with choice phrases

Note that the phrase for Lonely Woman / Own song is the same phrase that was used for choosing the harmoniser in the first place. This song is chosen as the core harmonisation song. When we are in harmonisation mode the code for this song can be used without reloading the harmonisation control surface.

Also note that the names of the songs are associated songs. Those songs could be played with them but they can also be used in free improvisations or related songs. More about the harmonisation sets can be read in chapter 7.

Within the harmoniser control surface we can also make some extra choices that are more general. Going up or down with the arpeggiator and within a chosen song going to the A, A', B etcetera part plus phrases to control moving the transposition of the entire harmonisation up or down an octave (with the code you step either to the right or to the left in the GUI surface):

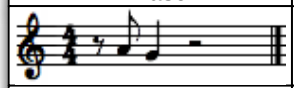
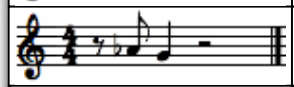
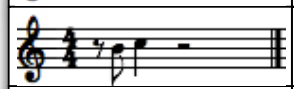
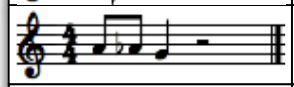
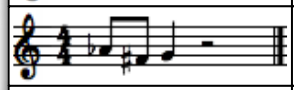
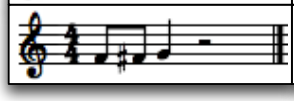
Short codes	
Phrase	**Action**
	*Play A part*
	*Play A' part*
	*Play B part*
	*Delay going Down*
	*Cancel / no Delay*
	*Delay going Up*

Figure 26 Examples of short phrases and their meaning.

Some of the actions that connect to phrases are hidden. When more voices are involved the volume of individual voices will be lowered for example. Other actions relate to the room acoustics. When a song is chosen that has a 'revered' character it may get placed in a big room while a song that has a more intimate or direct character will get much less reverberance. It is a deliberate choice to connect automation to the choices that are made, this frees the mind of the player for other tasks. Phrases that overtake control from normally automated tasks can easily be added.

6.5 The audio modules:

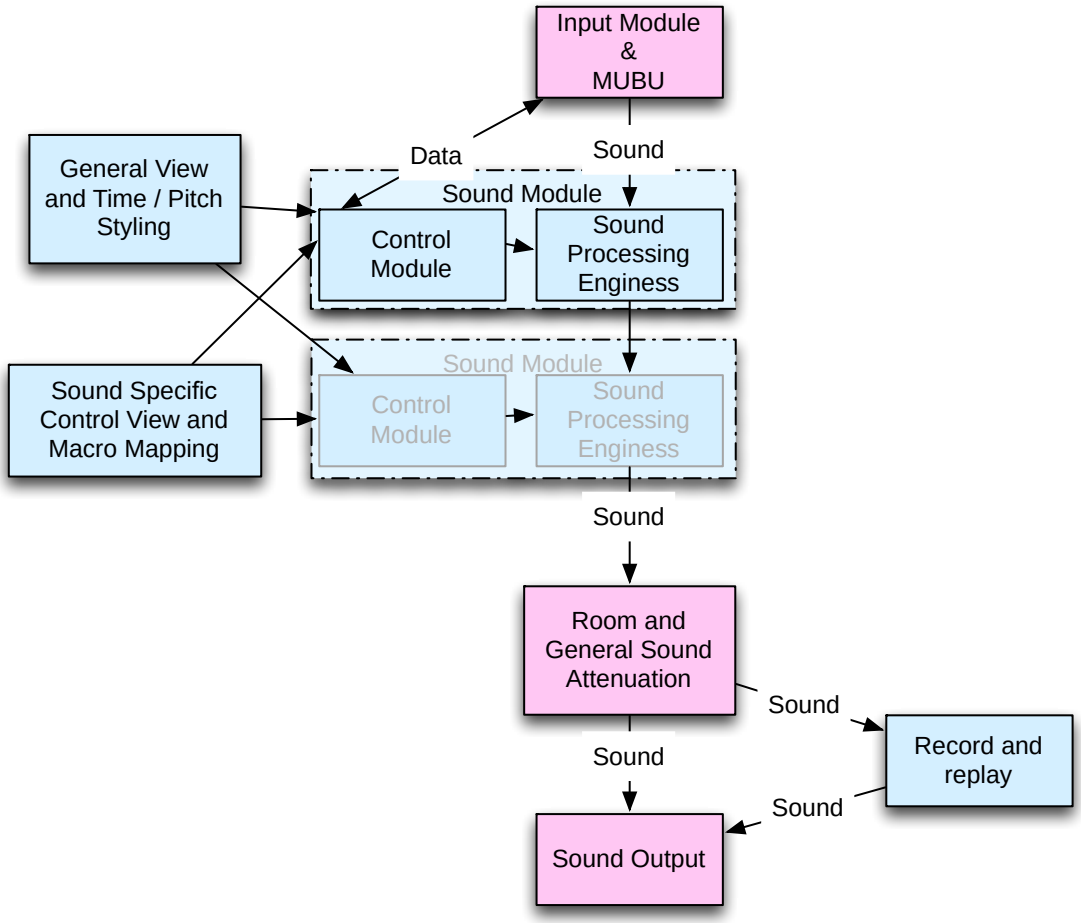
As mentioned before the original Electrumpet was organised around four audio streams. The control system was organised to facilitate this four audio stream basic design. Over the years control messages would become more and more global but the basic design did not change. The system could probably have been reorganised to fit the phrase system but it was a risk and it was immediately clear that it would add to the complexity and confusion and would not help to facilitate the enormous possibilities of the phrase system.

The importance of patch (performance) organisation was recognized in the interviews as mentioned. For the design of the new system the Jamoma framework has been an inspiration. Jamoma offers a framework that facilitates a modular approach to patching. Small modules can be patched flexibly together. Jamoma implements the Model View Controller (MVC) philosophy (Lossius et al., 2014).

Implementing Jamoma in this phase of the design process seemed a risk. The framework was new and the system as well. MVC philosophy in itself is very interesting when dealing with interactive complex musical software systems. MVC can be implemented without using the Jamoma framework. In MVC View models, control modules and model modules can be used together in different

relations. One control can be connected to different views and vice versa. Control and model can be used in the same manner.

So lets look at the most simple breakdown of the new Electrumpet system that still captures all of its interaction capabilities. The presented picture is a stark simplification of the system but it gives the basic principle of the design and should be kept in mind when details of the different parts of the system are discussed. Furthermore it is important to notice that the blue modules are modules that can be interchanged with other modules while playing while the purple modules are fixed although parameters within those modules can be controlled:



27 simplified Electrumpet system model

The data streams and audio streams that are shown in the model represent the normal operation. It is possible though that sound goes into the control module, gets analysed and the analysed data goes into the Sound Processing Engines for re-synthesis.

There are also extra data connections that are not drawn in the diagram for sake of clarity but there are quite some back and forth data exchanges. An example of this bigger complexity is for example that the direct trumpet sound is not mixed in the output when the harmonisation is simultaneous but it is when the harmonisation is arpeggiated.

6.5.1 Switching and developing Sound modules:
At the moment switching Sound Modules takes a long time. Up to six seconds is seen. The modules and engines have to be loaded in the DynamicDSP objects of Alexander Harker (Harker, 2011) and that takes time. Since all modules are stable now the system can be reprogrammed to load all modules and engines at start up which will get rid of the switching time.
While iteratively improving the system the modules can be more and more unified in the way they are controlled from the outside and still account for the specifics of each different sound module.

This unification process is partly implemented on the fly by using best practices from one module in another. The design of the four sound modules that are thus far implemented has gone back and forth in a process of continuous improvement. The arpeggiation of harmonies was first implemented in the analyses resyntheses module, which prompted the implementation in other modules.

6.5.2 Make up of the Sound Modules:
As can be seen in figure 10 a Sound module consists of a Sound control module and a number of Sound processing engines. This setup is chosen in order to be able to address different ways of Sound interaction in an organised manner.

Sound control module:
The sound control module is a translation module between information coming from sensors, the harmonisation module or the serial module. The module also controls the loading of the sound engines. The module divides control messages over the diverse sound engines or sends them first to the MUBU data track to be retrieved later.

Sound processing engines:
The engines have access to the MUBU audio track and get instructions from the sound control module informing them on what particular task has to be performed.

6.5.3 Make up of the input module and MUBU:
Gating:
In the input module two audio streams are captured: the normal microphone and the sound from an extra microphone on the mouthpiece. The second audio stream is used to gate the microphone sound to prevent sound from other sound sources to influence the processing.

Analyses pitch:
The yin~ external from Ircam is used to analyse the pitch and determine the noisiness of the sound. Some processing is done to extract a Midi note and together with the bonk~ external note onsets and note changes are registered. The midi note analyses can be tuned to the trumpet tuning.

Analyses tone-length:

The length of a note and the loudness gets estimated. These parameters are currently used by the Analyses Resyntheses module to determine decay time but could get more functions in other modules.

Filtering:
The incoming trumpet note gets filtered with a third order filter to remove all overtones from the sound. The remaining fundamental sound is used to trigger a glottal pulse in the corresponding module if the module is used.

MUBU sound:
The incoming sound and the filtered sound gets recorded in a MUBU sound track and is then available to the sound engines.

MUBU data:
Data comes in from the sound control module to be stored on the MUBU data track. This data gets placed in the future. At the same time the current data on the MUBU data track gets read out and send back to the sound control module.

6.5.4 Make up of the 'room and general sound attenuation' module:

Spat compressor:
There is an nine channel compressor on the nine channels of audio that can come into this module. The compressor settings are dependent on the active sound module. When the analyses resyntheses module is active, which can have high fluctuations in dynamics, a higher compressor setting is used then with other modules.

Spat:
Spat is mainly used for spatialization, equalizing and reverberance. The sound sources move slightly to create a little bit of movement in the voices in both distance and directness which creates a less static harmonisation sound. Spatialization and reverberance are controlled by the harmonisation choice that was made.

6.6 The eight current sound processing engines:

The sound processing engines do not only contain the sound processing engines themselves but also the data processing to map all the incoming parameters to the particular engine.

SuperVP.scrub~ engine:
SuperVP (super phase vocoder) is an Ircam external used in the harmonisation module to transpose upwards. . The phase vocoder takes care of a natural sounding transposed trumpet sound. The remix of the noise, transient and sinusoidal components is used as an effect.

Delayline engine:
This module is designed by the author and transposes downward using the onset and note change information generated by the yin~ and bonk~ objects.

(Appendix C.1). The principle of this module was inherited from the old system but redesigned and optimised using the gen codebox.

Mubu.granular~ engine:
This is again an Ircam external working directly on the MUBU sound buffer. The same sensor data is controlling the granular engines parameters that is also controlling the remix in SuperVP.scrub~ but differently mapped.

Glottal pulse engine:
This module is designed by the author and uses the filtered trumpet sound. The overtones are removed. Zero transitions of this signal are used as trigger for so called glottal pulses (ppgb, 2007). Downward and upward transposition is implemented similarly as the delayline transposition. Vibrato is added to get a more natural vowel sound. The vibrato swells with the onset of the tone following the frequency of natural singing (Prame, 1994). The principle of this module was inherited from the old system but redesigned and optimised using the gen codebox.

Vowel filter engine:
The vowel filter module works together with the glottal pulse signal as an input and uses Ircam vowel coefficients to filter the sound. The same sensor data is controlling the vowels that is also controlling the remix in SuperVP.scrub~ but differently mapped.

Analyses module:
This module is designed by the author. The module analyses the sound in its harmonic peaks and adds extra frequencies for separate channels if the harmonisation function is used.

Resyntheses engine:
The resyntheses engine takes in the peaks provided by the analyses module and places them in a ring matrix that is subdivided in 325 rows with 10 cent separation in frequencies, the amplitudes are kept in a separate corresponding matrix. The ring matrices are read out column by column for resyntheses and for reinsertion into the system. This happens with a fixed pace. The manner of reinsertion into the system is determined by the shift, delay and decay parameters.

Ring modulator engine:
The ring modulator engine is the first of the so called 2nd row sound processing units. A special implemented technique is ring modulation that leaves the harmonisation intact. By pitch shifting all the sounds in the harmoniser a fifth higher, or 3/2 times the frequency, and modulating this pitch with ½ the frequency, the complete harmonised sound stays recognizable but with a distinct edge to it.

Physical modeling engine:
The physical modelling engine is also a 2nd row sound processing unit. Currently it functions as a tuneable plate reverb.

6.7 Other relevant patch features

Gesture follower (digital valves):
The digital valve phrases are deducted from the measurement of the digital valves potentiometer values. First attempts with an existing gesture follower algorithm (GF from Ircam) were ok for up to five codes but worthless for larger sets. The decision was made to then hardcode the recognition. The measured values of the digital valves are typecast as on, off and in between states. Using this principle and some noise cancelling procedures the codes can be deduced with 100% accuracy provided the phrases are played 'neat' and the wireless connection is stable. The states of the valves are recorded within an FTM matrix and subsequently analysed. This analyses also provides the rhythm and the tempo with which the phrase was played. This works about 2/3 of the time. The rhythm and the tempo are used to provide the rhythm and tempo of the arpeggiated harmonization.

Sensor input:
The sensor input is received as OSC messages within the patch and pre-processed. The data from the ribbon controller for example is split into an on/off message and the value of the ribbon controller. The data is resend through the patch through send messages. The OSC message format is not used here, which might be a wise feature for future improvement.

Sensor shutdown when loading modules:
Loading patches in the DynamicDSP objects while they were active using FTM objects could easily crash the patch. When a new sound module is loaded in the DynamicDSP module the sensors are made inactive and the system is unresponsive until the sound module is fully loaded which is communicated through the GUI.

6.10 Chapter conclusion

The old Electrumpet system's flaws became apparent through the course of the PhD. The research amplified the need of a new system.

The new system has big potential for facilitating virtuosity through the use of a phrase system for control of the instrument.

The new system implements the Model View Controller strategy which makes it flexible and suitable for tinkering and experimentation.

Improvements are still needed to optimize the system: time sensitive sensor analyses should be done with hardware on the Electrumpet, The sound modules should all be loaded at start up in order to be able to quickly change from sound processing modules, the send and receive objects should be replaced by the OSC framework.

Chapter 7 Composing from the instrument:

7.1 Composing or designing:

In chapter 5 the term ‘composing from the instrument’ (CfrI) was introduced as a personal definition of the way in which the composition process is mainly implemented in the Electrumpet.

The question arises whether making an instrument is design or composition. The return question could be: “What is the difference between design and composition?”

The main argument to call it composition is that the design decisions are all made from a purely musical perspective. The persona model explained in chapter 5 shows how different personas look with different eyes upon the design process. Designing the Electrumpet is not purely a luthier issue. Virtuosity in musical environments is its main driving force.

The author has experience as a ‘notes on paper’ composer and as a composer of game pieces and the thought processes involved with those types of composing are very similar to the thought processes that are involved in designing the Electrumpet. For the treatment of harmonisation and rhythm this seams obvious but the same is true for a sense of what the combination of a sound plus an effect can do musically.

It is true that a lot of technical work has to be done before a sounding result can be produced. That technical work is always for the benefit of more versatility and thus versatile improvisations or for the improvement of the performance experience.

The novel techniques explained in this chapter are implementations on the Electrumpet but they can be transferred to other instruments.

In the last part of the chapters we will discuss the development of virtuosity on the instrument especially in relation to improvisation and how etudes can possibly help developing virtuosity on new instruments. A strategy used for learning the new Electrumpet system is explained.

7.2 CfrI in relation to the instrumental action on the Electrumpet

7.2.1 Compositional considerations from the instrumental persona:

In this section we will discuss the interaction with the instrument in relation to time and control. Ten years of experience with the instrument has led to a more narrowly defined approach. In the ten years of experience playing the Electrumpet in mostly improvised settings there has always been an ideal use of the instrument where the difference in handling the digital and acoustical control would not be consciously noticed anymore by the user. That ideal has always been the motivation to keep developing the instrument instead of taking it as it is and 'just make music'. The developments within the PhD have brought that ideal much closer

The Electrumpet is meant as an instrument to be used in relation to other instruments. There are quite a few example in the PhD where it is used solo but that is not the ultimate goal nor the philosophy behind it. The original design already has much of the same knobs and sliders on the instrument that are still there today. The only difference is that they can finally be put to use as they were intended which is explained in the last chapter.

As a player of the Electrumpet the interest has always been how scenarios could be developed that would stay 'close' to the direct playing. In the past the instrument has been used as a controller to process other instruments but that was always experienced as cheating on its original purpose. What was missing at such moments was Hardjowirogo's criteria for instrument design (Hardjowirogo, 2016) where she talks about Expressivity/Effort/Corporeality but also her remark on Learnability/Virtuosity: *"playing an instrument should appear more difficult than pressing a play button."* This also refers back to my comments in the Electrumpet context section on one of my inspirations within the jazz music context: Sean Bergin.

Although using the instrument as a controller on the direct sound of other instruments is more then pressing a play button it did not feel as much more either. Playing with previously recorded trumpet sound was not much better. Although actions on a controller may provide us with perfectly viable nice music as can 'pressing a play button' it is not the engaged action sought for in the Electrumpet. It is very similar to the distaste experienced with instruments like the EVI (Steiner, 2004) or the discontinued Morrison Digital Trumpet (Marshal, 2005). When familiar with the full expressivity and associated exhilarating experience that the acoustic trumpet can provide, a sample player, even when controlled with a 'trumpet style' controller, will feel lacking.

This does not mean that everything should be in complete direct control of the Electrumpet player. The author thinks that there are interesting examples of pieces and systems in which direct control is not exercised, but that still provide an interesting development direction for the instrument. Hearing Michael Young's piece *'prosthesis'* (Young, 2010), a free improvisation accompanied by an autonomous performance system based on an intelligent algorithm, performed live by ….. in Amsterdam in 2009 was inspirational. What struck was that the expressivity of … came back at a later moment in the piece in a transformed

manner thus providing …. with a nice counterpoint to his own improvisation efforts.

In concatenative syntheses (Schwarz, 2004) the audio is not looped literally but chopped up in small parts and then played back in any order the player or composer wishes. Schwarz build a software instrument around the idea called CataRT (Schwarz et al., 2006) and plays it using different controllers. Where Young's system provides an autonomous counterpoint Schwarz' system organises the previous musical material in such a way that there is easy access to it and the counterpoint can be controlled consciously. CataRT will be implemented in the future as soon as it is implementable in MUBU (Schnell et al., 2009). Implementation would mean that we still have to define the interaction with both the digital and the acoustic part of the Electrumpet.

Humans can not multi-task (Manhart, 2004). The human brain cannot be consciously busy on two activities at the same time. That leaves us with three forms of interaction considering live electronics on an instrument such as the Electrumpet: We leave part of the brain task to the computer, we alternate tasks from live electronics control to instrumental control, we integrate live electronics and instrumental tasks in such a way that they become an integrated brain activity. The second option with alternating tasks was dismissed in chapter 2 if it involved separate controllers for the live electronics. It has been an artistic choice not to develop the option on the Electrumpet at the moment either, forcing implementation of the other two options that are more interesting to the author.

Implemented on a small scale is the capacity of the computer to extract information from the trumpet playing and transfer it into control. Not implemented is intelligent choice making. Finding a good merge between elements of an 'autonomous performance system' and control from the Electrumpet remains a task for the future. The interest is currently in the construction of scenario's and control that merge electronic and acoustic control into one.

In order to better understand the issue we look at some examples of acoustic instruments that have similarly implemented these. The organ has the manuals and foot pedals that play the notes but in the same time stops have to pulled and pushed to control the registers of the organ. Brass players have used the so called 'plunger mute' in combination with the 'growl' technic (singing at the same time as playing trumpet which creates a rough sound) to mimic the human voice. Cootie Williams (trumpet player) and Ray Nance (trombone player) from the Ellington band both specialized specifically in the perfection of this technique to play solo's in a specific style (jungle), Rajesh Mehta (Mehta, 2013) controls a bird call whistle in combination with his trumpet playing. His techniques match very well with South Indian Carnatic music.

The techniques described in the last paragraph all have a direct impact on the sound. Using Electronics this directness can be stretched. In using the Electrumpet it is always remarkable to hear at what time scale you lose the connection with the sound that you just produced. An arpeggiator at a reasonable speed feels connected; too slow and this gets lost. Without precisely

knowing the time scale, which varies with the way information is added and the connectedness between material according to auditory scene analyses (Bregman, 1990), effects that are designed for the Electrumpet are designed to be connected; even while they may loose connection in practical use.

The effects that are currently implemented on the Electrumpet and were developed within the PhD are all designed with directness and connectedness in mind. In the newest version of the Electrumpet system this is all implemented using the before mentioned MUBU toolbox as its base. A technical description of effects can be found in chapter 6. In section 7.2.3 we explain the principle in non-technical terms.

7.2.2 Counterbalancing the instruments features:

In chapter 2 Tetzepi was introduced as the authors artistic context. The band played written out repertoire involving complex rhythm and also performed forms of collective and guided improvisation. This dualism was its strength and its weakness as the band never succeeded to integrate them into one artistic concept while it was acknowledged in both its defining characters. The dualism returned in the Electrumpet though slightly different it again represented a highly structured feature involving pitch next to the rest of the instrument that was sound oriented. At the start of the PhD the development of the interactive harmoniser had just started while at the same time more versatility was needed in the sound design of the instrument. For a time the two existed next to each other, with much more attention to the development of the interactive harmoniser. It was long unclear though where the connection between the two could be and it was not consciously developed.

Different strategies of harmonisation were developed that are discussed in section 7.3. These strategies were not concerned with issues of transition though. The harmoniser settings are very defining. Transitions between different harmoniser settings have to be prepared or are sudden which can be a complete conceptual break.

The addition in the new system of the arpeggio option to the interactive harmoniser has emancipated the use of non pitched sound in the harmoniser dramatically though. Depending on the effect used a noise that is harmonised sounds like filtered noise; a slightly different chord with pitches in the same range will sound like almost the same filtered noise. Arpeggiated though the movement in the sound can be heard first of all and secondly with much more detail. The effect of sound input on the effectiveness of the Electrumpet setting is discussed in section 7.4 and led to a more effective way of practising.

Suddenly the interactive harmoniser is not only a device for neat well organised pitched chords but can also be used in a much more abstract context. It is not a static sound but a moving sound. Playing with the sound parameters, both from the input side of the trumpet as the processing of that sound, using the arpeggiator scenario is an asset to the new instrument.

In order to explain the value of the arpeggio implementation for composition we will explain it schematically in paragraph 7.2.4, but first a short intermezzo describing the way the buffer was used before...

7.2.3 The use of live sampling before the system change:

The implementation of the arpeggiator in the Electrumpet is a departure from the way live sampling was used originally on the Electrumpet. The way live sampling was used was reminiscent of the way it is often introduced in the MAX programming language and also third party software. The Ableton software was designed around the principle. Schematically it looks like this:

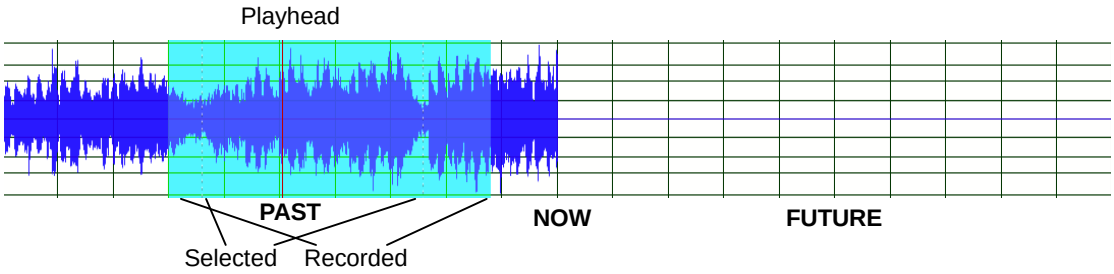


Figure 28 Traditional use of live sampling

Before the system change in the PhD the Electrumpet implemented four separate buffers in the same way. Looping was seldom used though because as mentioned before looping 'locks the sound' and hinders musical communication. Also, the interaction was too slow, the selection process means looking for 'the right piece of sound' and that is impossible during involved playing. This might also explain why the loop pedal is so successful in electronic music. The loop is selected in sync with the playing and after selection it is left alone.

7.2.4 Organising time in the new system:

In this section we will schematically look at the way the new system affords for CftI. It takes into account auditory scene analyses principles and the syncopation of acoustic and digital control.

For now we concentrate on that short time period before the now, the now and after the now and put that in a diagram. Neuroscientists and psychologists will argue that the now cannot be defined so explicitly but we will still use it for the sake of argument since we will move toward the system in which time is defined:

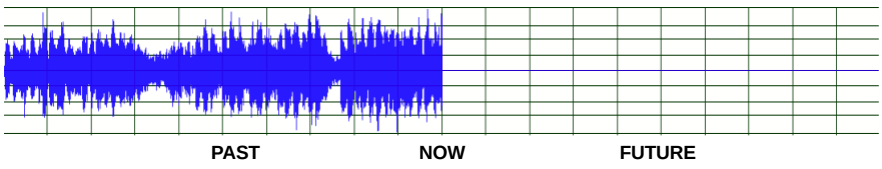


Figure 29 Representation of now for the Electrumpet player

The blue section represents the last four seconds of sound that was played. We are at the now so the future is still unknown.

Processing the now is impossible but processing the 'almost now' is, and if not too far in the past the perception will be that it is all happening in the same

moment. The playhead plays what has just been recorded. In the case of the interactive harmonizer on the Electrumpet there are actually a number of playheads (depending on the number of voices in the harmonization) all interacting on the same buffer. Each playhead belongs to a voice:

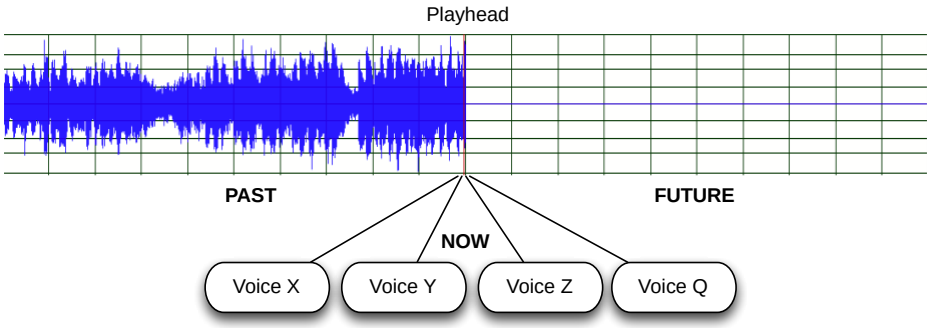


Figure 30 Simultaniously playing the harmonizer

The future is also treated. The future is unknown but can be scheduled. We can synchronize the playing of a note or sound with what is going to happen to that particular note or sound in the future. For example, the note has to be played again but a third up this time. If we take the last example we may decide that we want the note that is played at time now is arpeggiated with the rhythm 1 2 2 2. At time 'NOW' this rhythm and the transpositions needed on the original note are set out in the scheduler and the note is played by the playhead of the assigned voice at the moment that 'time' has reached the moment that the events were scheduled:

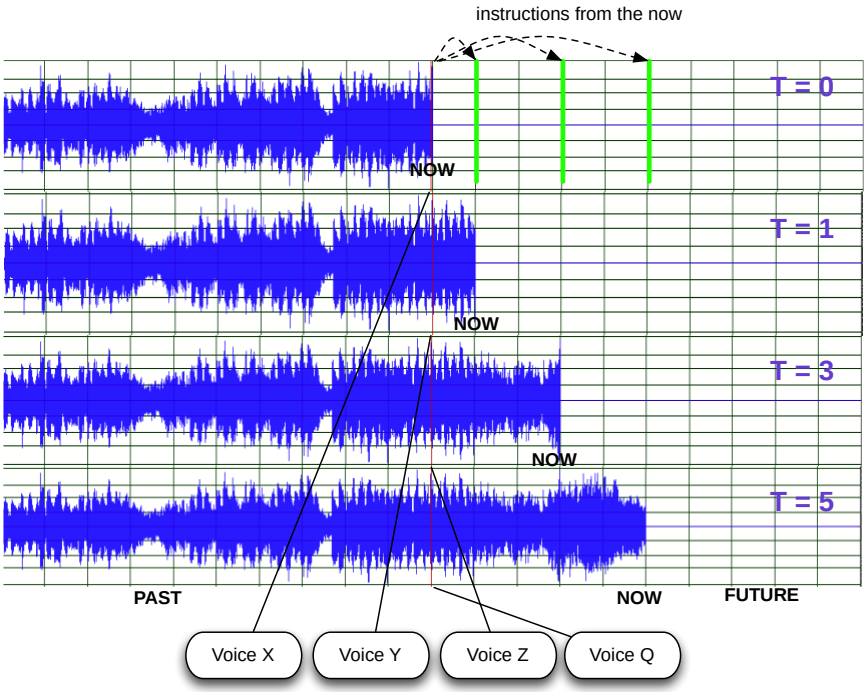


Figure 31 Scheduling the future

The most 'in the moment' way of playing is control over a number of parameters at moment 'T = 0' that determine the musical and processing parameters at the subsequent events. Since this idea evolved from the interactive harmonizer only

harmonisation can be determined at moment 'T = 0'. The rhythm and the tempo are determined by the rhythm and tempo with which the last phrase are played. Sound processing parameters are the same for all voices, the spatialization is predetermined by the harmonisation selection.

7.3 CfrI in relation to the harmonic action on the Electrumpet

The composer in this case is the creator of harmonic ordering and transitions. In this section we will mainly discuss the ideas behind the construction of different forms of interactive harmonisation. In the next section we will discuss its use.

7.3.1 Interactive harmonizer:

The interactive harmonizer is a concept. The construction of chords is determined by the currently played note (recognized with pitch recognition software) and the chord choice of the player. It features the capability to transpose upward and downward at the same time. The technical description of the implementation can be read in chapter 6. In this section we will discuss the construction of the chords and show some examples.

Scenarios:

Since the beginning of the PhD there has been experimentation with different ways of implementation of the interactive harmonizer. At the moment there are 4 scenarios:

7.3.2 Chords per note defined from a counterpoint perspective:

In this type of interactive harmonization transposition upward and downward is implemented with a fixed middle voice (fig. 15 and 16) or fixed middle harmonization. There are two harmonization chord families implemented. A narrow family and a wide family. The note in the middle of each chord is the note played acoustically the other two notes are generated:

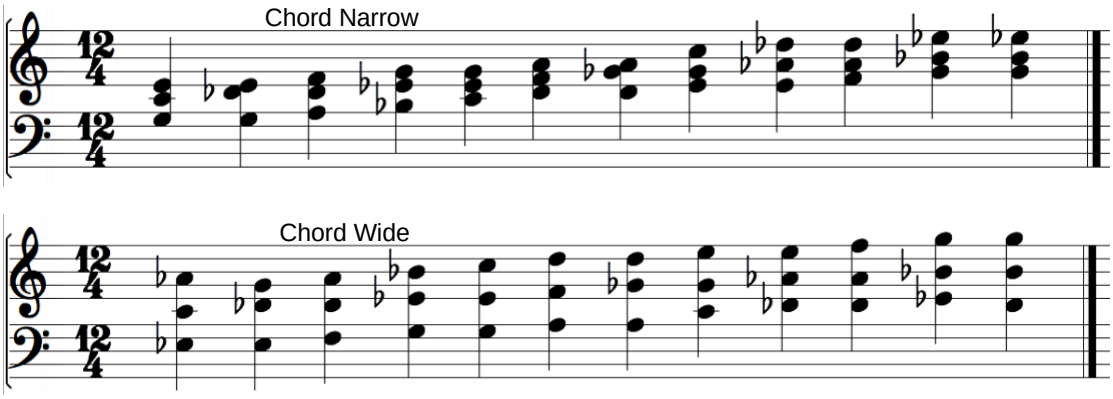


Figure 32 chord families narrow and wide for 'Echo of a Requium'

Alternating those two chords while playing different notes on the acoustic trumpet we can create a contrapuntal melody of three voices:

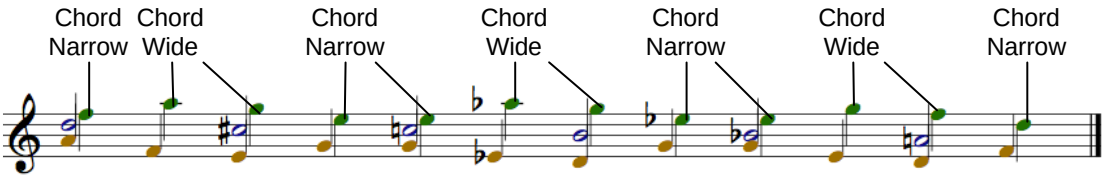


Figure 33 Example using the harmoniser on a part of 'Echo for a Requium'

[‘Echo for a Requium played with granular synthesis’]

A few more use cases have been designed that use the same principle. This scenario and the scenario with a fixed chord in the middle and moving outer voices sound clear. Experiments with chords with more moving voices tend to be messy. This use scenario has not been further explored since the upgrade of the system however.

7.3.3 Abstract sets for which pitch recognition is less important:

The first inspiration for this type of chords was ‘Central Park in the Dark’ by Charles Ives (1906). The piece uses blocks of chords with one or two prominent intervals creating an atmospheric background. Originally those chords are played by violins. The chords are subdivided in four families, again the chromatic scale in the middle starting at C is the note played on the acoustic trumpet.

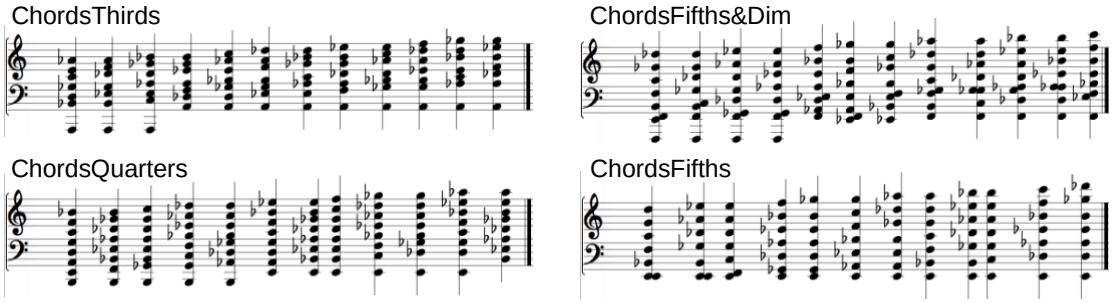


Figure 34 The Ives chord families

[Improvisation Ives]

The abstract spherical chords of Ives were useful in improvisation settings and more sets followed. A set of chords based on the overtone series was created and based on this set another set was created for the Fokker Organ. These sets and all the sets before as well were based on microtonal tunings, which is discussed in section 7.4.

7.3.4 Sets of chords defined per note in the fixed chord order of a tune:

With the upgrade of the system the interactive harmonizer became more responsive. Sets with more chords were suddenly much easier to use. Harmonized jazz tunes with interactive harmonisation even in improvisations became a possibility. These were used in a jazz performance as a proof of concept. As an example here the tune Nancy with the laughing face (van Heusen, 1942).

The tune is subdivided in three parts A, A', B. When playing the tune the player can change from set to set using short valve codes (see chapter 6), the numbers after the chords give the lengths of the chords:

A part:
{ G- 4 C7 4 FΔ 2 Bb7 2 A- 2 Abº 2 G- 4 Eø 2 A7 2 D- 2 G7 2 G- 2 D7 2 }
A' part:
{ G- 4 C7 4 FΔ 2 Bb7 2 A- 2 Abº 2 G- 4 Eø 2 A7 2 D- 2 Eb7 2 FΔ 2 A7 2}
B part:
{ D- 12 G7 2 Eb7 2 FΔ 2 D- 2 G- 2 A7 2 D- 2 G7 2 G- 2 D7 2}

On the Electrumpet this looks like this when we start at chord number one:

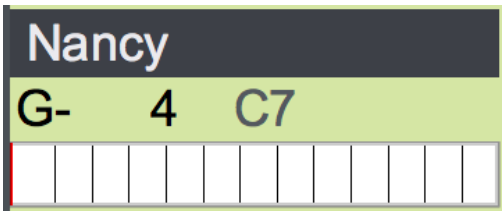


Figure 35 The Harmoniser GUI on the Electrumpet

This song can be found oin the repertoire. The 'Engelbewaarder' songs.

7.3.5 Counterpoint voices in a fixed chord order of a tune:

The previous songs with fixed chord order use harmonisation but they do not really pay much attention to voice leading (The chords are meant to be used for improvisation as well). Silence (Charlie Haden, 1983) uses counterpoint in the individual voices. The composition is build adding one voice at the time with simple valve combinations. The individual voices can be followed. In this case the chords stay the same for each note within a chord family. Improvisation has a fixed background.

Silence two voices. The acoustic trumpet is the upper voice and stayes the same while other voices join:

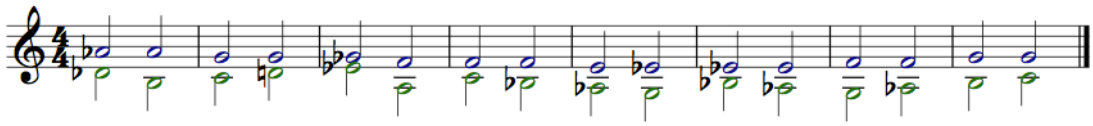


Figure 36 Silence two voices, trumpet is upper voice.

The culmination is when all voices join. Transposition is upward and downward:

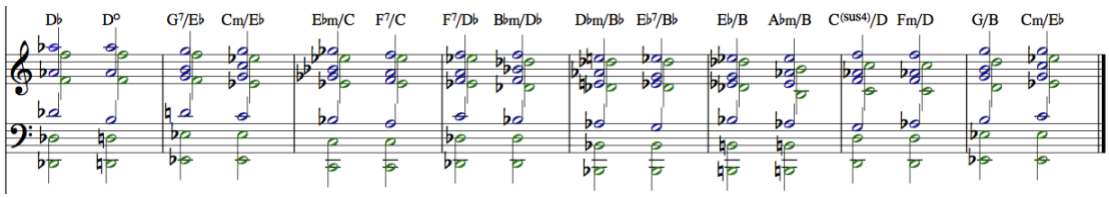


Figure 37 Silence with all voices joined, the trumpet is the 3rd voice

Silence (Charlie Haden, 1983)

The Silence idea of adding voices has been transferred to a few other pieces. This piece has also been very instrumental in fine tuning the balance of the harmonizer. Each time a voice is added the volume of the individual voices gets slightly softer. The song is also used to balance the different effects in relation to each other. In the end the song is used to implement all the features within the Electrumpet that could be considered 'post production' of the instrument: wave-shaping, compression, spatialization, reverb.

Section conclusion:

The interactive harmoniser is a unique feature of the Electrumpet. The search is not so much for new harmonisation sets but more for new harmonisation scenarios. The treatment of individual voice leading is important for the strength of the harmonization experience. The composition of original harmony sets has not been a priority. There are a number of original sets but also a number of sets implementing harmonisations or arrangements that are transferred from existing repertoire.

7.4 Arpeggiating chords:

In section 7.2.3 we discussed the time organisation of the new Electrumpet system. The chords on the Electrumpet can now be played arpeggiated by scheduling the moment they are played.

This is a big asset to the instrument. It becomes particularly interesting when te arpeggiation is done overlapping and the timing of the playing is synchronised with the playing of the acoustic trumpet. In harmonisation settings with wider intervals played up tempo, for example the Ives harmonisation, auditory segregation effects (Bregman & Campbell, 1971) will group arpeggiated pitches together in individual melodies.

Ives arpeggiated halve valve

Some codes (as discussed in chapter 6) may still change in order to facilitate a larger ordering. The ordering of notes in arpeggiated harmonised delays is now 'top down', 'bottom up' and 'simultaneous' using 2 note codes. The orderings 'out in', 'in out', 'steps up' and 'steps down' are already considered. There are also options in which a note gets repeated.

A next step in the construction of arpeggiation has to be done carefully. The possibilities may not be endless if the system still has to be playable. Nesting arpeggiation scenarios under specific harmonisation sets can combine versatility with easy access.

7.5 Microtonality:

Microtonality is another typical example of the author being influenced by a specific personal circumstance as was discussed earlier. Working as a student assistant in the physics department for a few years guiding students in projects that handled psychoacoustics an interest was born and teaching psychoacoustics

now at the University of the Arts Utrecht has heightened that interest. In the course there is also attention to tuning systems.

When the effort of the implementation of the interactive harmoniser started it was only logical to use just intonation for tuning the chords. Chords are tuned based on the ratios of small natural numbers.

There are a few reasons to use just intonation over equal temperament. The chords produced with just intonation are perceived as more sonore which enhances their power. The movement of individual notes between chords becomes more obvious then in equal temperament. This last feature is extra important since it introduces individuality of those voices. It makes that the harmonisation on the Electrumpet stands out in comparison to a regular synthesizer.

There has been some time spend within the PhD to construct a system that could do the tuning of more complex chords automatically. That effort is postponed for the moment but would help speeding up the harmony construction process.

7.6 CfrI in relation to improvisation on the Electrumpet

In the last section we discussed the interactive harmoniser. The interactive harmoniser is not an effect but it is part of the repertoire of the Electrumpet. The harmonisation sets are ways of organising tonal material on the Electrumpet. The sets may be conceived as a piece but once on the Electrumpet they can be transformed, used together or used with a non pitched sound.

In section 7.2 we described the organisation of time and rhythm on the Electrumpet. There is also the added option to transpose the harmonisation, both continuous and in discrete octave steps.

These are not all the features that we can play with. At the moment we have four different playback options: Delay line/vocoder combination, vowel-follower, granular syntheses, analyses resyntheses. Each of these playback options has some features that can be controlled with the sensors on the Electrumpet (see chapter 6) and some of the control originates in the acoustic sound (pitch, volume, noisiness, note-length).

The number of options is not yet exhaustive, but the number of combinations is much larger since control features are if possible transferred so they can be used in every situation and combination.

The number of options is large enough to play a varied repertoire. The next step is to get grip on that repertoire.

7.7 Learning the instrument and developing virtuosity, etudes:

Next to the inspiration from Sam Pluta the mere thought about developing virtuosity on the Electrumpet as it used to be and the translation of those thoughts into etudes incited the need for the redevelopment of the Electrumpet. The kind of virtuosity wished for most was operating with speed in an improvisation context (see chapter 4).

Methodology to learn new instruments is still lacking in the NIME literature. Jennifer Butler constructed a series of etudes using MAXMSP (Butler, 2008). The etudes concentrate on the control of specific elements of an instrument turning them on and off at the right time. While this is a good strategy for learning where your controls are, it takes out a part of the decision making process and this is the part important for an instrument in an improvisation context.

In order to make informed decisions on what to use in a certain situation the first step is to know the instrument. Knowing the instrument is different from knowing an acoustical instrument. The physical connection that exists between player and instrument makes that the player can predict what sound will come out when the interaction is performed in a certain way even if that particular sound was never produced before. This prediction does not always need to be exact but should capture the musical intention. The sound scope of electronic instruments though is vastly bigger and the prediction of the sound that will come out is only determined by the designer. It needs a lot of practice to develop this.

What acoustical and electro-acoustical instruments do have in common is that 'knowing the instrument' means having a representation in mind of the sound emitted by the instrument. There are of course musicians that don't want to know the instrument and want to play with its unpredictability.

7.7.1 'Knowing the instrument', a methodology:

In search for a method to describe the sound coming out of the Electrumpet the idea was to make an inventory of all the sounds possible. Hopefully an inventory would lead to a method to describe the sounds.

A table was made in which all possible combinations of trumpet sound input could be combined with the then available effects and controls and every combination would be recorded. The duration of the recording was not determined beforehand which led to an interesting process. A few of the cells are filled to give an impression. The whole table can be found in appendix D.

Sound effect	**Control effect**	**Playing Style**	**type**	**Normal Harmonisation**	**Recording Harmonisation**	**Harmonisation with Delay**	**Recording Harmonisation + Delay**
delayLineSuperVP	Harmonisation	attack	Jazz	Not very interesting			
			Minor interactive	Works nicely with close position vs open position. Special attention to attacks on the rim of the moutpiece and higher pitch added	recording_5_3_2018__20_58_24		
			Ives				
			Abstract	Works best with harmonisations including	recording_5_3_2018__21_9_50.		

				upwards transposition (fundamental, not octaves). Try to get pitch recognision on a high pitch.	recording_5_3_2018__21_11_4		
		noise	Jazz				
			Minor interactive				

Making an inventory of sound transformed to making an inventory of the usefulness of the combinations. Short improvisations of two minutes were played, listened back to and judged on their usefulness in a playing situation. The fixed parameters make it easy to explore within such a given situation and it is possible to play with only a few parameters. The activity was also engaging, inspiring and motivating. The hours of practice spend on the instrument instead of tinkering went up. Exploring the edges of expressivity of a certain setting was rewarding.

The versatility of the new instrument was as expected much greater then the old instrument. The systematic approach of using all the control phrases and sensor control also led to discoveries in practising that were real treasure troves (see the sheet and the recordings to get an impression).

The systematic exploration informed tinkering; some artefacts were discovered that originated in the old Electrumpet system. Because of the focus within a realm or piece it was easier to deduce what could be improved.

The filling of the sheet became a systematic practice method. Much more time and focus then before was directed at actual playing and listening. There are now a number of clear mental images that represent successful combinations of input. It is also clear though that while being very busy writing down this PhD thesis the recall of a number of other mental images is faltering.

This method is still in its infancy and should be further developed. The excel sheet is not very practical in keeping overview of the activities. A MAX patch or even better a WEB site with a little bit of smart interaction would be far better then what it is now. If that system can be personalized it will also be beneficial to other players of new instruments.

7.7.2 Etude, game pieces and the bucket system:

In Tetzepi, the band mentioned in chapter 2, the use of improvisation was common ground. Different forms of improvisation were applied. Improvisation over chord chances but also collective improvisation, free improvisation, conduction and game pieces. These were implemented with differing rates of success.

At the NIME conference in Baton Rouge, 2015 the author was asked to participate in an improvisation piece using an interactive system. The piece was called the Bucket list (Dahlstedt, Nilsson, & Robair, 2015). This piece provided the players with very simple choices guided by the system mostly determining

the role of the player and nothing more. The piece was interactive. Players could drop their favourite duo, trio or quartet and their roles into the bucket.

The strength of this piece was that it combined freedom with just a little bit of direction. It was not determined what should be played only when and in what role.

This piece inspired to make an adaptation to use with the author's students at the HKU (University of the Arts Utrecht). The piece can have any number of players and instead of an embedded system the players look at a screen with coloured dots. The piece has been played often and the students like to do it. Our students are not well versed though to know what it enthrals to take on roles as the game asks of them. Of course it is the teachers' responsibility to give feedback to the students based on this.

The next step is an individual interactive etude system. This system should not take care so much about handling the knobs on the instrument as described by Butler in the beginning of this section. The player should get prepared for improvisation situations in which he or she could end up and in the same time get confronted with the effectiveness of the instrument in such a situation.

The method from the last section could well be a first step in the direction of such an etude system. The explorative attitude that is normal for an expert performer like the author could likely be simulated by providing the player with visual cues that force a certain role by association. This is pure speculation though.

This visual system from the last paragraph can be a first step to a bigger visual system for composition that also provides cues for transformation. The piece that the author performed with the Fokker Organ uses such an island structure. The piece starts with an existing piece, then transforms to another island using Ives chords that is totally improvised, then transforms to the microtonal environment of the Fokker Organ that is also improvised and ends with a transformed version of the beginning tune.

Swarm: Electrumpet & Fokker Organ (Hans Leeuw, 2018)

7.8 Chapter conclusions:

'Composing from the instrument' is what is most developed on the Electrumpet during the PhD. It was a deliberate choice to focus on the instrument and start composing from it. New strategies that could be helpful especially for other hyper instrument players have been developed and explored. The instrument has grown much more powerful and versatile because of it.

The transition between a composed environment and an improvised environment can much easier be bridged then before the development of the new Electrumpet system but there is still room for improvement on that front.

Learning true virtuosity on the instrument as the author had envisioned it long ago is now within reach. Methodology to structurally practice the instrument is

developed and can be transferred to other electronic instrument player / developers.

The author acknowledges that the instrument has matured substantially but that the anchor into the intended musical environment has only just been restarted. Original repertoire that truly is on the border between structured and free improvisation as was played by Tetzepi will have to be developed in the next face.

Chapter 8 Conclusion and future work:

This chapter concludes the PhD thesis but certainly not the further development of the Electrumpet. The use of the model and the research in general, not in the least including the intensive analyses of the interviews with fellow PIDs, have brought new insights and has humbled biased opinions towards fellow instrument designers. The analyses of the instrument, has not only brought improvements but also stressed the importance of continued development.

One of the main insights coming from the application of the model was that the tension between personas can be used to improve the design. The tension between the improviser and the designer persona was needed to radically change the instrument's system and a healthy cooperation between the tinkerer and designer personas can prevent new design stagnations. The performer, the improvisor, the instrumentalist and the composer all have a different position towards new material for the instrument. These different viewpoints are needed to keep moving forward in diverse direction.

The interaction with the instrument is now codified through a system that uses the existing trumpet virtuosity, the musical memory and the musical imagination trained on the acoustic trumpet for digital virtuosity on the Electrumpet. This transfer of virtuosity from acoustic instruments to digital instruments is often talked about in musical instrument design. The keyboard is an example that implements this in a one-on-one transfer from the piano. The implementation on the Electrumpet is different, however. It is a more complex musical mapping that still manages to simplify its use.

The persona model was only used in the context of the design of the Electrumpet. It has proven its use in the redesign and redevelopment of that particular instrument and will continue to do so. The persona model has not yet been tested in a broader discourse. The NIME community is the ideal venue to disseminate the model and discuss its validity in other use cases. Diverse presentations for colleagues and as a guest speaker on other Universities suggest interest for the fresh view that the model offers to instrument designers.

The use of the phrase system on the Electrumpet is a big leap forward in its usability in a context where quick changes are needed. Moreover it has led the way to a much clearer organized system. Together with Sam Pluta's system for operation in a multidimensional space (Pluta, 2012). Both systems share some traits that are valuable as a best practice for other instrument designers.

Composition in relation to the Electrumpet has been defined as 'composition from the instrument'. This form of composition is somewhat related to algorithmic composition but stands on its own in relation to the interaction through sensors and acoustic input. There is a treasure-trove of possibilities that can be implemented. The persona model keeps check on the development through the validation of priorities from the different personas.

8.1 Future work

Future work on the Electrumpet is again discussed in relation to the different persona's and follows some of the reflection in chapter 5.

8.1.1 Instrumentalist:

The first task is working on ergonomics with some added support probably in EVA foam to make the new digital sensors easily available for the index and middle finger of the left hand.

After solving the ergonomics issues the new sensors can be explored for new opportunities. The use of these continuous sensors for expressive interactions should get precedence over the implementation of new modules but the simultaneous development with TSU's might be interesting.

Reintroducing more of the single voice elements present in the Electrumpet before the PhD. Introducing modules on the single input channel might be an option previous to granular synthesis, the phase vocoder or just directly to the output.

The hand that moves in front of the 3D-touchpad does not have any reference. Experiments with EMS (electric muscle stimulation) feedback were positive enough to possibly try it out further on the Electrumpet. Since the Electrumpet now has a local Wi-Fi network it can be implemented wireless fairly easy. It is also a multi-disciplinary research interest within the University of the arts Utrecht.

Similarly, exploring the haptic feedback connected with the ribbon controller a little bit more also seems an interesting proposition: 'An example application that seems at immediate reach of current tactile interfaces is to create illusory effects of loudness change by varying the intensity of vibratory feedback.' (Fontana, Papetti, Järveläinen, Avanzini, & Giordano, 2018, p. 68)

In cooperation with the artisan luthier both left- and right-hand support has to be improved. Left hand support is needed to reach the new electronic valves more freely. Right hand support is needed for single handed play without pressing the new sensors on the 2nd and 3rd valves.

Ribbon controller discreetness. Do something with speed?

9-axis. Clear though is that only the up and down movement of the instrument will be implemented for continuous expression as mapping in a horizontal direction will again hamper free movement too much. It can also be a feature that is not used/implemented continuously.

8.1.2 Performer:

and intended to intensify the performer role after completely finishing the PhD process with the Electrumpet as the central focus for performance. The performer itself as the central figure for the design of a piece (think spatialisation).

One of the incentives of the clip microphone was the ability to move freely with the instrument. True freedom can only be reached by becoming completely wireless. The idea is to implement a wireless system for the clip microphone and to do sound analysis from the gate microphone directly on the PocketBeagle. Successful pitch tracking experiments on the PocketBeagle mean that pitch tracking can be implemented. More importantly though onset detection with low latency has to be implemented as well.

One of the scenario's that is not yet explored is spatialisation in combination with the 9-axis sensor. A performance with the wavefield synthesis system in The Hague is on the wish list for a few years now and can be implemented as soon as the instrument is truly wireless.

In general, with a well-functioning distance sensor, the opportunities to be more visibly expressive will grow.

8.1.3.1 Hardware and artisan luthier:

There is still some work that has to be done on the new version of the instrument:

- The software is not optimized yet and there are a few implementations missing.
- The ergonomics issues for the instrumentalist have to be solved
- There is quite a bit of noise from hollow cavities
- The ribbon controller casing has to be cut a little smaller for the digital valves

The MacBook tray on the microphone stand is too heavy for both transportation and stability. A new version in aluminium, closer to the mic stand should be manufactured.

8.1.3.2 Sound luthier:

Sound luthier improvements on the Electrumpet should focus on scenarios that implement the expressive functionality of the three continuous sensors in impactful expressive mapping.

Additive synthesis is still implemented without using the MuBu system that is the core sound organization tool within the Electrumpet and allows for uniform control interfaces for all main sound modules. New functionality in MuBu should help to implement additive synthesis in MuBu.

The newly added physical modelling modules of modalys need further exploring possibly adding some of the expressive opportunities with the new sensors creating virtual but physical exciters.

The modules in the second layer can currently only be loaded in parallel. Some new combined serial with parallel functionality might be implemented in dynamicdsp~ or it might be implemented within the system. The goal is to make the sound design in this layer more versatile

The voice synthesis module needs some work to broaden its sound quality.

8.1.4 Improviser:

The main goal is to keep working on new material that broadens the scope of the instrument. That means other functionality in tonal organisation besides the harmoniser like some form of looped play or concatenative synthesis like CataRT.

Working on new modules there has to be an effort to afford for the multidimensionality aspect of the instrument so that it becomes increasingly easy to morph from sound to sound and interaction to interaction continuously without unintended sudden change. Sudden change should be possible as well of course but controlled or intentionally uncontrolled in certain isolated scenarios.

Improvising with others will keep functioning as a means to develop new functional ideas and to scrutinize the functionality of existing ones.

8.1.5 Tinkerer:

The tinkerer has no plans but the tight line between tinkering and redesign as described in this thesis should be maintained meaning that rigorous redesign is needed when tinkering starts to create a mess.

8.1.6 Composer:

The implementation of TSU's (temporary semiotic units) is thus far only exploratory. Some ideas to implement them within the realm of the harmoniser delay combination should be further worked out and implemented.

Through the new spatialization interface in combination with the delay and the harmonizer, there are new opportunities to implement some psychoacoustic effects on the Electrumpet like a creative implementation of Diana Deutch' scale and octave illusions. In so doing, the harmonizer's abstract repertoire suitable for improvisation will be expanded.

The implementation of independent automated sound layers still does not have a high priority, but a few successful rhythmical implementations that did not sound looped from Gerry Jaeger and Andi Otto might be an incentive to look again.

8.1.7 Designer:

The 3D-touchpad sensor replaces the infrared sensor for distance but the touch sense capability can be used as well. This can be a minor alternative for the phrase system on the valves to move to another ‘discreet state’ that cannot be reached when one hand is occupied or it can be completely dedicated to control distinct types of interaction for distance control. This should be further investigated.

The harmonisation module is getting more complex and new ideas keep coming. A fundamental redesign that even more rigorously names objects should keep clutter away.

Much of the OSC-preset information is scattered in multiple ftm-dictionaries over the instrument. Although some of it has been centralised it seems wise to take a look at how to organise all the information as time will get lost looking for it. Waiting longer to implement this will increase the time needed to redesign.

When such an OSC-preset information system is implemented, it becomes easier to record this information as well. Automatically recording a timeline with sensor information and phrase codes next to the audio is handy for analysis, learning and virtuosity development.

Finally, the phrase system does not need practice as in speed of playing but speed of remembering the right phrase for the right action can be trained. Also steering the player into presets that are seldom used can be advantageous. Again the OSC-preset system can be an asset to accomplish this.

References:

Ableton. (2001). Ableton. Retrieved November 28, 2019, from Ableton

Agostini, A., & Ghisi, D. (2013). Real-time computer-aided composition with bach. *Contemporary Music Review*, *32*(1), 41–48. https://doi.org/10.1080/07494467.2013.774221

Alpern, A. (1995). *Techniques for Algorithmic Composition of Music*. Retrieved from https://pdfs.semanticscholar.org/d701/dd6cdc82ed544422c553dab59426f759d558.pdf

Bailey, D. (1992). *Improvisation*. Da capo press.

beagleboard.org foundation. (2017). pocketBeagle. Retrieved November 25, 2019, from http://beagleboard.org/pocket

BERGSTROEM-NIELSEN, C. (2016). Keywords in Musical Free Improvisation. *Music and Arts in Action*, *5*(1), 11–18. Retrieved from http://www.musicandartsinaction.net/index.php/maia/article/view/improvkeywords/101

Bijsterveld, K., & Schulp, M. (2004). Breaking into a world of perfection: Innovation in today's classical musical instruments. *Social Studies of Science*, *34*(5), 649–674. https://doi.org/10.1177/0306312704047171

Bogaards, N., Röbel, A., & Rodet, X. (2004). Sound Analysis and Processing with AudioSculpt 2. *Proc. Int. Computer Music Conference (ICMC)*.

Bongers, B. (1998). An interview with …. *Computer Music Journal*, *22*(1), 13–24. https://doi.org/10.1038/nrg1356

Bosch. (2014). BNO055. Retrieved November 25, 2019, from https://www.bosch-sensortec.com/bst/products/all_products/bno055

Bovermann, T., de Campo, A., Egermann, H., Hardjowirogo, S. I., & Weinzierl, S. (2016). Musical instruments in the 21st century: Identities, configurations, practices. In *Musical Instruments in the 21st Century: Identities, Configurations, Practices*. https://doi.org/10.1007/978-981-10-2951-6

Bregman, A. S. (1990). *Auditory scene analysis: The perceptual organization of sound*. MIT Press.

Bregman, A. S., & Campbell, J. (1971). Primary auditory stream segregation and perception of order in rapid sequences of tones. *Journal of Experimental Psychology*, *89*(2), 244–249. https://doi.org/10.1037/h0031163

Burtner, M. (2004). A Theory of Modulated Objects for New Shamanic Controller Design. In Y. Nagashima, Y. Ito, & Y. Furuta (Eds.), *Proceedings of the International Conference on New Interfaces for Musical Expression* (pp. 193–196). Retrieved from http://www.nime.org/proceedings/2004/nime2004_193.pdf

Butler, J. (2008). Creating Pedagogical Etudes for Interactive Instruments. In A. Camurri, G. Volpe, & S. Serafin (Eds.), *Proceedings of the International Conference on New Interfaces for Musical Expression* (pp. 77–80). Retrieved from http://www.nime.org/proceedings/2008/nime2008_077.pdf

Carpentier, T., Noisternig, M., Warusfel, O., Carpentier, T., Noisternig, M., Warusfel, O., … Warusfel, O. (2015). Twenty Years of Ircam Spat : Looking Back, Looking Forward. *41st International Computer Music Conference (ICMC), Denton, TX, United States*, 270–277. https://doi.org/hal-01247594f

Constanzo, R. (2017). *Composition, Performance, Improvisation, and Making Things, sitting in a tree : Me-Me-Me-Me-Me-Me-Me* (University of Huddersfield). Retrieved from http://www.rodrigoconstanzo.com/thesis/

Cook, P. R. (2009a). Re-Designing Principles for Computer Music Controllers : a Case Study of SqueezeVox Maggie. In N. Zahler, R. B. Dannenberg, & T. Sullivan (Eds.), *Proceedings of the International Conference on New Interfaces for Musical Expression* (pp. 218–221). Retrieved from http://www.nime.org/proceedings/2009/nime2009_218.pdf

Cook, P. R. (2009b). Re-Designing Principles for Computer Music Controllers : a Case Study of SqueezeVox Maggie. In N. Zahler, R. B. Dannenberg, & T. Sullivan (Eds.), *Proceedings of the International Conference on New Interfaces for Musical Expression* (pp. 218–221). Retrieved from http://www.nime.org/proceedings/2009/nime2009_218.pdf

Çorlu, M., Muller, C., Desmet, F., & Leman, M. (2015). The consequences of additional cognitive load on performing musicians. *Psychology of Music*, *43*(4), 495–510. https://doi.org/10.1177/0305735613519841

Crawford, M. (2016). *The world beyond your head*. Penguin UK.

Creighton, E. (2010). Jogo an explorative design for free play. *Proceedings of IDC2010: The 9th International Conference on Interaction Design and Children*, 178–181. https://doi.org/10.1145/1810543.1810565

Csikszentmihalyi, M. (2014). Flow. In *Flow and the Foundations of Positive Psychology* (pp. 227–236). https://doi.org/10.1007/978-94-017-9088-8

Dahlstedt, P., Nilsson, P. A., & Robair, G. (2015). The Bucket System - A computer mediated signalling system for group improvisation. *Proceedings of the International Conference on New Interfaces for Musical Expression*, 317–318. Retrieved from http://www.nime.org/proceedings/2015/nime2015_171.pdf

De Bono, E. (2017). *Six thinking hats*. Penguin UK.

Dobrian, C., & Kop, D. (2006). The E in NIME : *Proceedings of the International Conference on New Interfaces for Musical Expression*, 277–282.

Dörner, A. (2018). Composition for Trumpet and Electronics. Retrieved December 3, 2019, from https://www.youtube.com/watch?v=cFvnK0zPzf0

Emmerson, S. (2007). *Living Electronic Music*. De Montfort University, Leicester, UK.

Fels, S. (2000). Intimacy and Embodiment : Implications for Art and Technology. *Proceedings of the 2000 ACM Workshops on Multimedia. ACM, 2000.*, 13–16.

Fléty, E., & Maestracci, C. (2011). Latency improvement in sensor wireless transmission using IEEE 802.15. 4. *Proceedings of the International Conference on New Interfaces for Musical Expression*, (June), 409–412. Retrieved from http://www.nime.org/proceedings/2011/nime2011_409.pdf

Francis, S. (2013). Piezobarrel wind instrument pickups. Retrieved May 19, 2018, from http://www.piezobarrel.com/

Freed, A. (2008). Application of new Fiber and Malleable Materials for Agile Development of Augmented Instruments and Controllers. In A. Camurri, G. Volpe, & S. Serafin (Eds.), *Proceedings of the International Conference on New Interfaces for Musical Expression* (pp. 107–112). Retrieved from http://www.nime.org/proceedings/2008/nime2008_107.pdf

Freed, A., Wessel, D., Zbyszynski, M., & Uitti, F. M. (2006). Augmenting the Cello. In N. Schnell & F. Bevilacqua (Eds.), *Proceedings of the 2006 International Conference on New Interfaces for Musical Expression (NIME-06)* (pp. 409–413). Retrieved from http://www.nime.org/proceedings/2006/nime2006_409.pdf

Gibson, J. J. (1979). *The ecological approach to visual perception*. Houghton-Mifflin.

Gurevich, M., & Treviño, J. (2007). Expression and Its Discontents : Toward an Ecology of Musical Creation. In C. Parkinson, G. D'Arcangelo, & E. Singer (Eds.), *Proceedings of the International Conference on New Interfaces for Musical Expression* (pp. 106–111). Retrieved from http://www.nime.org/proceedings/2007/nime2007_106.pdf

Haddad, D. D., Xiao, X., Machover, T., & Paradiso, J. A. (2017). Fragile Instruments: Constructing Destructible Musical Interfaces. *NIME 2017 Proceedings of the International Conference on New Interfaces for Musical Expression*, 30–33. Retrieved from http://www.nime.org/proceedings/2017/nime2017_paper0006.pdf

Hannon Teal, K. (2012). Beyond the Cotton Club: The persistence of Duke Ellington's jungle style. *Jazz Perspectives*, *6*(1–2), 123–149. https://doi.org/10.1080/17494060.2012.721292

Hardjowirogo, S. I. (2016). Musical instruments in the 21st century: Identities, configurations, practices. In T. Bovermann, A. de Campo, H. Egermann Weinzierl, S. Hardjowirogo, & S. Weinzierl (Eds.), *Musical Instruments in the 21st Century: Identities, Configurations, Practices* (pp. 9–25). https://doi.org/10.1007/978-981-10-2951-6

Harker, A. (2011). AHarker Externals. Retrieved February 8, 2015, from http://eprints.hud.ac.uk/id/eprint/16254 website: http://alexanderjharker.co.uk/Software.html

Harrison, J. (1998). Sound, space, sculpture: Some thoughts on the 'what', 'how' and 'why' of sound diffusion. *Organised Sound, 3*(2), 117–127.

Hautbois, X. (1991). Temporal Semiotic Units. Retrieved May 28, 2018, from http://www.labo-mim.org/site/index.php?2013/03/29/225-temporal-semiotic-units-tsus-a-very-short-introduction

Hildebrand, D., Lopes, M., Hoelzl, H., & Campo, A. de. (2016). Musical instruments in the 21st century: Identities, configurations, practices. In T. Bovermann, A. de Campo, H. Egermann Weinzierl, S. Hardjowirogo, & S. Weinzierl (Eds.), *Musical Instruments in the 21st Century: Identities, Configurations, Practices* (pp. 335–363). https://doi.org/10.1007/978-981-10-2951-6

Howard, D. M., & Angus, J. A. S. (2017). Acoustics and Psychoacoustics. In *Acoustics and Psychoacoustics*. https://doi.org/10.4324/9781315716879

Ircam. (1998). Forumnet. Retrieved from http://forumnet.ircam.fr/

Iversen, O. S., Halskov, K., & Leong, T. W. (2013). Values-led participatory design. *CoDesign : International Journal of CoCreation in Design and the Arts*, *8*(April 2013), 87–103.

Jenkinson, A. (1994). *Beyond Segmentation*. (march), 60–72.

Jordà, S. (2005). *Digital Lutherie Crafting musical computers for new musics ' performance and improvisation*. Universitat Pompeu Fabra.

Jordà, S. (2011). Keynote Lecture 3 : Digital Lutherie and Multithreaded Musical Performance : Artistic , Scientific and Commercial Perspectives. *Proceedings of the International Conference on New Interfaces for Musical Expression*, (June), 2011. Oslo, Norway.

Jordà, S., Kaltenbrunner, M., Geiger, G., & Alonso, M. (2006). The reacTable. *ACM SIGGRAPH 2006 Sketches on - SIGGRAPH '06*, 91. https://doi.org/10.1145/1179849.1179963

Kartadinata, S. (2003). The gluiph: a nucleus for integrated instruments. *Proceedings of the 2003 Conference on New Interfaces …*, 1–4.

Krefeld, V. M. W. (1990). The hand in the web: An interview with Michel Waisvisz. *Computer Music Journal*, *14*(2), 28–33.

Kvifte, T. (2008). On the description of mapping structures. *Journal of New Music Research*, *37*(4), 353–362. https://doi.org/10.1080/09298210902731394

Lamb, R., & Robertson, A. (2011). Seaboard : a New Piano Keyboard-related Interface Combining Discrete and Continuous Control. *Proceedings of the International Conference on New Interfaces for Musical Expression*, (June), 503–506. Retrieved from

http://www.nime.org/proceedings/2011/nime2011_503.pdf

Leeuw, H. (1997). Tetzepi. Retrieved May 30, 2018, from http://www.tetzepi.nl/

Leeuw, H. (2009). The Electrumpet , a Hybrid Electro-Acoustic Instrument. *Proceedings of the International Conference on New Interfaces for Musical Expression*, 193–198.

Leeuw, H. (2012). The electrumpet , additions and revisions. *NIME 2012 Proceedings of the International Conference on New Interfaces for Musical Expression*, 258–259.

Leeuw, H. (2017). Hyper-instruments and Musicianship. In *A NIME Reader* (pp. 335–351).

Lester, M., & Boley, J. (2007). The effects of latency on live sound monitoring. *Audio Engineering Society - 123rd Audio Engineering Society Convention 2007*, *2*, 704–723.

Libet, B. (1973). Electrical stimulation of cortex in human subjects and conscious sensory aspects. In E. Iggo (Ed.), *Handbook of sensors physiology Vol. 2* (pp. 743–790). Heidelberg: Springer.

Lossius, T., Place, T., De La Hogue, T., Wolek, N., Baltazar, P., & Rabin, J. (2014). Model-View-Controller separation in Max using Jamoma. *Proceedings - 40th International Computer Music Conference, ICMC 2014 and 11th Sound and Music Computing Conference, SMC 2014 - Music Technology Meets Philosophy: From Digital Echos to Virtual Ethos*, 1573–1580.

Loubet, E. (2000). Laptop performers, compact disc designers, and no-beat techno artists in Japan: Music from nowhere. *Computer Music Journal*, *24*(4), 19–32. https://doi.org/10.1162/014892600559498

Machover, T. (Media L. (1992). *A Progress Report 1987-1991*.

Manhart, K. (2004). "The limits of multitasking." 14.5 (): 62-67. *Scientific American Mind*, *14*(5), 62–67.

Marshal, S. (2005). Morrison Digital Trumpet. Retrieved May 26, 2018, from http://www.digitaltrumpet.com.au/

Marshall, M. T., & Wanderley, M. M. (2006). Vibrotactile Feedback in Digital Musical Instruments. *Proceedings of the International Conference on New Interfaces for Musical Expression (NIME06)*, 226–229. Retrieved from http://marktmarshall.com/data/media/writings/marshallnime06.pdf

McPherson, A. (2012). TouchKeys: Capacitive Multi-Touch Sensing on a Physical Keyboard. In G. Essl, B. Gillespie, M. Gurevich, & S. O'Modhrain (Eds.), *Proceedings of the International Conference on New Interfaces for Musical Expression*. Ann Arbor, Michigan: University of Michigan.

Mehta, R. (2012). Mehta-trumpets. Retrieved May 18, 2018, from Youtube website: https://www.youtube.com/watch?v=9bAas8Nr1Oo

Mehta, R. (2013). Rajesh Mehta's "Drumpet." Retrieved May 10, 2016, from Youtube website: https://www.youtube.com/watch?v=q_TpBbVDib0

Microchip. (2012). GestIC-technology. Retrieved November 25, 2019, from https://www.microchip.com/design-centers/capacitive-touch-sensing/gestic-technology

Miller, R. (1996). *modal jazz composition & harmony*. Advance Music.

Mitchell, T., Madgwick, S., Rankine, S., Hilton, G., Freed, A., & Nix, A. (2014). Making the Most of Wi-Fi: Optimisations for Robust Wireless Live Music Performance. *Proceedings of the International Conference on New Interfaces for Musical Expression*, 251–256.

Morris, L. D. (2006). Conduction® is. *Contemporary Music Review*, *25*(5–6), 533–535. https://doi.org/10.1080/07494460600990588

Neill, B. (1992). Ben Neill's WEBsite. Retrieved February 15, 2015, from Mutantrumpet website: https://benneill.com/

Neill, B., Moog, R., Behrman, D., & Abraham, R. (2017). The Mutantrumpet. *NIME 2017 Proceedings of the International Conference on New Interfaces for Musical Expression*, 489–490.

Nijs, L., Lesaffre, M., & Leman, M. (2009). THE MUSICAL INSTRUMENT AS A NATURAL EXTENSION OF THE MUSICIAN. *The 5th Conference of Interdisciplinary …*, 132–143.

Nika, J., & Chemillier, M. (2012). Improtek, integrating harmonic controls into improvisation in the filiation of omax. *ICMC 2012: Non-Cochlear Sound - Proceedings of the International Computer Music Conference 2012*, 180–187.

NIME Community. (2001). NIME WEBpage. Retrieved February 19, 2015, from http://www.nime.org

Nowitz, A. (2008). Alex Nowitz. Retrieved December 1, 2019, from https://nowitz.de/

Palacio-quintin, C. (2008). Eight Years of Practice on the Hyper-Flute : Technological and Musical Perspectives. *NIME 2008 Proceedings of the International Conference on New Interfaces for Musical Expression*, 293–298.

Pluta, S. (2012). *Laptop Improvisation in an Multi-Dimensional Space*. COLUMBIA UNIVERSITY.

Pollack, I. (1968). The Apparent Pitch of Short Tones. *The American Journal of Psychology*, *81*(2), 165–169.

ppgb. (2007). Glottal Puls. Retrieved from http://www.fon.hum.uva.nl/praat/manual/PointProcess__To_Sound__phonation____.html

Prame, E. (1994). Measurements of the vibrato rate of ten singers. *The Journal of*

the Acoustical Society of America, *96*, 1979. https://doi.org/10.1121/1.410141

Reid, S., Gaston, R., Honigman, C., & Kapur, A. (2016). Minimally Invasive Gesture Sensing Interface (MIGSI) for Trumpet. *Proceedings of the International Conference on New Interfaces for Musical Expression*, 419–424.

Reina, R. (2015). *Applying Karnatic Rhythmical Techniques to Western Music* (first). Amsterdam: Ashgate.

Resnick, M., Myers, B., Nakakoji, K., Shneiderman, B., & Pausch, R. (2005). *Design Principles for Tools to Support Creative Thinking*. Retrieved from http://repository.cmu.edu/isr

Resnick, M., & Rosenbaum, E. (2013). *Design, make, play: Growing the next generation of STEM innovators* (M. Honey & D. E. Kanter, Eds.). Routledge.

Rieber, L. P. (2001). Designing learning environments that excite serious play. *Annual Meeting of the Australasian Society for Computers in Learning in Tertiary Education, Melbourne, Australia*.

Roederer, J. G. (2009). The Physics and Psychophysics of Music. In *The Physics and Psychophysics of Music*. https://doi.org/10.1007/978-0-387-09474-8

Rovan, J. B., Wanderley, M. M., Dubnov, S., & Depalle, P. (1997). Instrumental gestural mapping strategies as expressivity determinants in computer music performance. *Kansei, The Technology of Emotion. Proceedings of the AIMI International Workshop*, 68–73.

Ryan, J. (1991). Some remarks on musical instrument design at STEIM. *Contemporary Music Review*, *6*(1), 3–17.

Schiesser, S., & Schacher, J. C. (2012). SABRe : The Augmented Bass Clarinet. *NIME 2012 Proceedings of the International Conference on New Interfaces for Musical Expression*, 109–112.

Schnell, N., Borghesi, R., Schwarz, D., Bevilacqua, F., & Muller, R. (2005). {FTM} --- Complex Data Structures for {Max}. *Proceedings of the 2005 International Computer Music Conference*, 9–12. Madrid, Spain.

Schnell, N., Röbel, A., Schwarz, D., Peeters, G., & Borghesi, R. (2009). MUBU & friends - Assembling tools for content based real-time interactive audio processing in MAX/MSP. *Proceedings of International Computer Music Conference*, (Icmc), 423–426.

Schnell, N., & Schwarz, D. (2005). GABOR , MULTI-REPRESENTATION REAL-TIME ANALYSIS / SYNTHESIS. *Proc. of the 8th Int. Conference on Digital Audio Effects (DAFx'05),* 1–5. Madrid, Spain.

Schwarz, D. (2004). Data-driven concatenative sound synthesis (Ircam Centre Pompidou). https://doi.org/10.1080/09298210600696691

Schwarz, D., Beller, G., Verbrugghe, B., & Britton, S. (2006). REAL-TIME CORPUS-

BASED CONCATENATIVE SYNTHESIS WITH CATART. *Proc. of the 9th Int. Conference on Digital Audio Effects (DAFx-06),* 279–282. Montreal, QC, Canada.

Sethares, W. A. (1994). adaptiveTuning.pdf. *Journal of Society of America*, *96*(1), 10–18.

Sharp. (1999). Sharp distance sensor.

Steiner, N. A. (2004). The electronic valve instrument (evi), an electronic musical wind controller for playing synthesizers. *The Journal of the Acoustical Society of America*, *115*(5), 2451–2451.

Tanaka, A. (2000). Musical Performance Practice on Sensor-based Instruments. In M. M. W. and M. Battier (Ed.), *Trends in Gestural Control of Music,* (pp. 389–406). Ircam - Centre Pompidou.

Tenney, J., & Gilmore, B. (2019). *Changing the Metaphor : Ratio Models of Musical Pitch in the Work of Harry Partch , Ben Linked references are available on JSTOR for this article : RATIO MODELS OF MUSICAL PITCH IN THE WORK OF*. *33*(1), 458–503.

Tetzepi. (2011a).

Tetzepi. (2011b). Tetzepi. Retrieved May 23, 2008, from muziekencyclopedie website: http://www.muziekencyclopedie.nl/action/entry/Tetzepi

Texas Instruments. (2013). drv2605 haptic motor controller. Retrieved November 29, 2019, from http://www.ti.com/lit/ds/symlink/drv2605.pdf

Tormoen, D., Thalmann, F., & Mazzola, G. (2014). The Composing Hand: Musical Creation with Leap Motion and the BigBang Rubette. In B. Caramiaux, K. Tahiroglu, R. Fiebrink, & A. Tanaka (Eds.), *Proceedings of the International Conference on New Interfaces for Musical Expression* (pp. 207–212). Retrieved from http://www.nime.org/proceedings/2014/nime2014_536.pdf

Trail, S., Tavares, T. F., Godlovitch, D., & Tzanetakis, G. (2012). Direct and surrogate sensing for the Gyil african xylophone. In G. Essl, B. Gillespie, M. Gurevich, & S. O'Modhrain (Eds.), *Proceedings of the International Conference on New Interfaces for Musical Expression*. Ann Arbor, Michigan: University of Michigan.

Tremblay, P.A. (2017). Tuning to trust: System calibration as creative enabler. *43rd International Computer Music Conference and the 6th International Electronic Music Week*, 15–20.

Tremblay, Pierre Alexandre, & McLaughlin, S. (2009). Thinking Inside the Box: A New Integrated Approach to Mixed Music Composition and Performance. *Proceedings of the International Computer Music Conference (ICMC 2009), Montr{é}al, Canada, August 16-21, 2009*, (Icmc), 379–386. Retrieved from http://eprints.hud.ac.uk/4081/

Ubiquity. (2005a). airMAX. Retrieved November 25, 2019, from https://www.ui.com/airmax/rocketm/

Ubiquity. (2005b). airMAX Sector. Retrieved November 25, 2019, from https://www.ui.com/airmax/airmax-sector-antenna/

UITTI, F.-M. (2000). An Adventure. In J. Zorn (Ed.), *Arcana: Musicians on Music* (Vol. 1, p. 67). Granary Books.

Uitti, F. M. (2018). Frances Marie Uitti, biography.

Van der Schyff, D. (2013). The Free Improvisation Game: Performing John Zorn's Cobra. *Journal of Research in Music Performance*. https://doi.org/10.21061/jrmp.v0i0.727

Whitehead, K. (1998). *New Dutch Swing*. Billboard Books.

Wright, M. (2005). Open Sound Control: An enabling technology for musical networking. *Organised Sound*, *10*(3), 193–200. https://doi.org/10.1017/S1355771805000932

Yarosh, S., Radu, I., Hunter, S., & Rosenbaum, E. (2011). Examining values: An analysis of nine years of IDC research. *Proceedings of IDC 2011 - 10th International Conference on Interaction Design and Children*, 136–144. https://doi.org/10.1145/1999030.1999046

Young, M. W. (2010). Identity and Intimacy in Human-Computer Improvisation. *Leonardo Music Journal*, *20*, 97.