MASTER’S THESIS

DEXTORIA

A system to control electric guitar effects via sound-producing gestures, integrated into the typical ecology of guitarists

Submitted at

FH JOANNEUM Graz

Universität für Musik und darstellende Kunst Graz

Communication, Media, Sound, and Interaction Design (Master)

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Graz, 2023

Abstract – English version

In electric guitar playing, effects are predominately controlled via foot using floor-based effects pedals. However, they are limited in their control possibilities, difficult to access and challenging to control while playing. New control systems have been developed that try to mitigate these shortcomings, however, they appear to be not well integrated into the common guitar playing environment.

This Master's thesis set out to design and evaluate "Dextoria" – a control system that allows to further leverage the sound-producing hand gestures of guitarists. Dextoria consists of two setups: the left-hand setup enables guitarists to switch between two effects loops according to the position of the fretting hand along the guitar's neck. The right-hand setup allows effects with an expression pedal input to be controlled by the movements of the strumming/picking hand. Dextoria enables a smoother and more intimate control of effects and is conceived to control off-the-shelf effects pedals without dependency on computers and/or specifically programmed effects, thereby integrating into guitarists' existing live setups.

Dextoria was qualitatively evaluated with nine guitarists, conducting interviews as well as usability tests. The results of the interviews strengthened the use case for the Dextoria system. During the usability tests, Dextoria could be integrated into all participants' setups. The system did not substantially hamper conventional playing techniques and succeeded in facilitating effects control for guitarists by making control more dynamic and expressive as well as promoting freedom of movement on stage. In some cases, the left-hand setup appeared somewhat restrictive regarding the access to possible fret positions and the right-hand setup could not completely substitute all expression pedal functions. Finally, Dextoria provided guitarists with a new perspective to effects control with both setups stimulating creative playing styles.

Dextoria introduces guitarists to a novel, innovative approach to effects control while, at the same time, enabling them to keep using their favorite effects pedals.

The following links lead to two demonstration videos of Dextoria:

https://phaidra.kug.ac.at/o:130874

https://phaidra.kug.ac.at/o:130875

Abstract – German version

Beim E-Gitarre spielen werden Effekte überwiegend mit dem Fuß über Effektpedale auf dem Boden gesteuert. Diese sind jedoch in ihren Steuerungsmöglichkeiten begrenzt, umständlich zu erreichen und während des Spielens schwierig zu steuern. Forschungsprojekte haben neue Steuersysteme entwickelt, die versuchen, diese Mängel zu beheben, aber diese scheinen sich nicht gut in die konventionelle Gitarrenumgebung integrieren zu lassen.

Ziel dieser Masterarbeit war es, "Dextoria" zu entwickeln und zu evaluieren – ein Steuerungssystem, das es ermöglicht, die klangerzeugenden Handbewegungen von Gitarrist:innen zusätzlich zu nutzen. Dextoria besteht aus zwei Setups: Das linke Hand-Setup ermöglicht Gitarrist:innen, zwischen zwei Effektschleifen umzuschalten, je nach Position der Greifhand am Gitarrenhals. Mit dem Setup für die rechte Hand können Effekte mit Expression-Pedal-Eingang durch die Bewegungen der Schlag/Zupfhand gesteuert werden. Dextoria ermöglicht eine intuitivere und genauere Effektsteuerung und ist so konzipiert, dass es handelsübliche Effektpedale unabhängig von Computern und/oder speziell programmierten Effekten steuert und sich so in das bestehende Live-Setup von Gitarrist:innen integrieren lässt.

Dextoria wurde qualitativ evaluiert, indem Interviews und Usability-Tests mit neun Gitarrist:innen durchgeführt wurden. Die Ergebnisse der Interviews stärkten den Anwendungsfall für das Dextoria-System. Während der Usability-Tests konnte Dextoria in die Setups aller Teilnehmer:innen integriert werden. Das System behinderte die konventionellen Spieltechniken nicht wesentlich und konnte die Effektkontrolle für Gitarrist:innen erleichtern, indem es die Kontrolle dynamischer und ausdrucksstärker machte und die Bewegungsfreiheit auf der Bühne förderte. In manchen Fällen wirkte das Setup für die linke Hand etwas restriktiv auf die Auswahl möglicher Bundpositionen, und das Setup für die rechte Hand konnte nicht alle Funktionen eines Expression-Pedals vollständig ersetzen. Schlussendlich eröffnete Dextoria den Gitarrist:innen eine neue Perspektive auf die Effektsteuerung, wobei beide Setups kreative Spielweisen anregten.

Dextoria bietet Gitarrist:innen einen neuen, innovativen Ansatz für die Effektsteuerung und ermöglicht es ihnen gleichzeitig, ihre bevorzugten Effektpedale weiter zu verwenden.

Die folgenden zwei Links führen zu zwei Demonstrationsvideos von Dextoria:

https://phaidra.kug.ac.at/o:130874

https://phaidra.kug.ac.at/o:130875

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I also confirm that I have prepared this thesis in compliance with the principles of the FH JOANNEUM Guideline for Good Scientific Practice and Prevention of Research Misconduct.

I declare in particular that I have marked all content taken verbatim or in substance from third party works or my own works according to the rules of good scientific practice and that I have included clear references to all sources.

The present original thesis has not been submitted to another university in Austria or abroad for the award of an academic degree in this form.

I understand that the provision of incorrect information in this signed declaration may have legal consequences.

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Die vorliegende Arbeit ist in dieser Form zur Erreichung eines akademischen Grades noch keiner anderen Hochschule im In- oder Ausland vorgelegt worden.

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Acknowledgements

I want to thank Marian Weger who coached me through the difficult beginnings of this project during semesters two and three and helped me to develop the foundations of what has now become this Master’s thesis.

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List of abbreviations

Amp	(Guitar) amplifier
BLE	Bluetooth Low Energy
BPM	Beats per minute
cm	Centimeter
CS	Chip Select
FX	Effects
GHz	Gigahertz
GPIO	General-purpose input/output
IDE	(Arduino) Integrated Development Environment
I^2C	Inter-Integrated Circuit
IMU	Inertial measurement unit
IoT	Internet-of-Things
IR	Impulse Response
JFET	Junction-gate field-effect transistor
LCD	Liquid Crystal Display
LED	Light-emitting diode
MIDI	Musical Instrument Digital Interface
MISO	Master In Slave Out
mm	Millimeter
MOSI	Master Out Slave In
m/s^2	Meter(s) per second squared
nm	nanometers
OLED	Organic light-emitting diode

OSC	Open Sound Control
PA system	Public address system
PD	Pure Data
SCK	Serial Clock
SDI	Serial Data In
SDO	Serial Data Out
SPAD(s)	Single Photon Avalanche Diodes
SPI	Serial Peripheral Interface
ToF (sensor)	Time-of-flight sensor
TRS	Tip-Ring-Sleeve
V	Volt
VCSEL	Vertical Cavity Surface-Emitting Laser
V_{dd}	Voltage (drain, drain)
V_{ss}	Voltage (source, source)

1. Introduction

Since its invention at the end of the 1940s, the electric guitar has been a pioneering instrument and subject to substantial sonic experimentation and augmentations. Recent augmentation efforts have been identified to be not well integrated into the typical ecology of guitarists. For instance, several scientific projects (Hödl and Fitzpatrick 2013; MacConnell et al. 2013), and commercially available products (Genki Instruments n.d.) aim to provide more real-time control over sound effects. However, these products force players to interrupt their natural playing movements to access and handle the additional control interfaces. Other studies (Lähdeoja, Wanderley, and Malloch 2009; Konovalovs et al. 2017; Donovan and McPherson 2014) aim to incorporate ancillary gestures, i.e., movements supporting sound-producing gestures (Jensenius et al. 2010, under "Functional Aspects of Musical Gestures") of guitarists to add another dimension of control possibilities to the guitar. The disadvantage of this approach is that guitarists may need to learn these newly conceived, unfamiliar movements and subsequently, concentrate on these new kinds of movements next to their usual playing movements, adding another level of complexity. Finally, some projects such as the “Magpick” (Morreale, Guidi, and McPherson 2019) or the “MIDI pick” (Vanegas 2007) succeed in using sound-producing gestures to control additional effects. However, along with the other projects mentioned, these work via digital sound processing (PD, Max MSP, etc.) and, hence, rely on a computer and/or are restricted to specifically programmed effects. The conventional live guitar rig, however, tends to consist of a guitar going through various hardware effects pedals into an amplifier. It can therefore be argued that requiring guitarists to incorporate computers into their effect chain constitutes a major intrusion into the natural playing environment of guitarists.

In the light of these observations, this Master’s thesis sets out to develop and evaluate a system that addresses the above-mentioned shortcomings regarding the integration of additional sonic control possibilities into the typical ecology of guitarists. Hence, the main research hypothesis of this Master’s thesis reads as follows:

Design and evaluate a sonic control system that:

1. Is ecologically valid in terms of live performance setup
2. Is ecologically valid in terms of conventional playing techniques
3. Relieves guitarists from additional cognitive load associated with controlling guitar effects
4. Enables a smoother and more flexible performance

The idea is to develop a system consisting of a left-hand setup and a right-hand setup that allows to register the sound-producing gestures (Jensenius et al. 2010, under "Functional Aspects of Musical Gestures") that are performed during playing in order to extend the sonic control possibilities of the electric guitar. These kinds of gestures are chosen because guitarists are already familiar with these gestures and do not need to learn them anew so that a high degree of intimacy (Fels 2004, p. 672) can be achieved more easily. Furthermore, as they are performed anyways, guitarists do not need to focus on other, potentially distracting gestures during their performances. To take the system's extent of integration into guitarists' typical ecology one step further, the developed system does not rely on computers and is not restricted to specifically programmed audio effects. Instead, it is conceived to integrate and control off-the-shelf (guitar) effects pedals.

For the sake of simplicity, the system described above will be henceforth called "Dextoria". The name stems from the word "dexterity" which refers to "the ability to perform a difficult action quickly and skillfully with the hands" (Cambridge Dictionary online, s.v. "dexterity."). As the Dextoria system's primary control input stems from the guitarist's hand movements, this name was deemed appropriate.

2. Outline of thesis

This Master's thesis is divided into four parts:

The first part of the thesis examines the topic on a theoretical basis. After providing a brief overview of the history of the electric guitar, challenges of augmenting electric guitars are explored and, subsequently, concepts influential to Dextoria's design are explained.

In the second part, research regarding the characteristics/qualities of the ecology of guitarists is carried out in order to make a use case for the Dextoria system and further refine its design requirements. Firstly, a theoretical examination involving literature reviews and analyses of online sales rankings is performed. The results obtained are then complemented by the findings of a qualitative study which is explained in more detail in part four of the thesis below.

The third part of the thesis is concerned with the documentation of development of the Dextoria system.

The fourth part involves a qualitative study comprised of interviews and usability tests of Dextoria involving nine guitarists. The interviews aim to provide additional insights on the features of the ecology of guitarists. The usability tests involve an extensive practical evaluation of Dextoria with electric guitar players testing the system. The nine participating guitarists have substantial live experience and come mainly from different sub-genres of rock but also jazz or experimental music. To analyze the data gathered, the qualitative content analysis by Mayring was applied (Mayring 2015).

3. Electric guitar augmentation

The following chapters serve as an introduction to the field of electric guitar augmentation, providing a brief overview of the history of electric guitar augmentation as well as describing associated challenges.

3.1. History of electric guitar augmentations

“Augmented instruments, also referred to as extended or hybrid instruments or hyperinstruments, are acoustic (sometimes electric) musical instruments extended by the addition of several sensors, providing performers the ability to control extra sound or musical parameters.” (Miranda & Wanderley 2006, p. 21). According to Lähdeoja et al. (2010 pp. 39-41), the electric guitar can be considered a highly augmented instrument since it is basically an acoustic guitar whose sonic possibilities were and still are extended by electromechanical and digital means.

The electric guitar, as the name suggests, remains at its core a guitar. Especially as far as physical features are concerned, the electric guitar is largely based on the acoustic guitar, including its main construction and its use of the chromatic scale. In the first half of the 20th century, it was tried to alter the guitar in a way that makes it possible to play at higher volumes and essentially make guitars louder. With augmentations based on acoustic means, such as larger bodies, failing to achieve increased volume while maintaining playability, the focus shifted to electric amplification with the invention of the solid-body electric guitar at the end of the 1940s. By using electric technology, the original, acoustic sound source became part of an electro-acoustic chain, comprised of the guitarist, the instrument, analog or digital effect processors and an amplifier with the sound being perceived via loudspeakers and no longer by the actual instrument. Apart from higher possible volumes, the electrification of the guitar inspired new ways of thinking and creating, paving the way for new timbres and playing techniques never achieved before with conventional acoustic guitars (Lähdeoja et al. 2010, pp. 39-40). At the same time however, Lähdejoa (2008, p. 54) notes that the electric guitar maintains a very significant characteristic of its acoustic pendant, namely the connection between gesture and sound through direct energy transduction. While in the case of the electric guitar, this connection involves an electromagnetic pick-up used to transduce the mechanical energy of the vibrating strings directly into voltage, it nevertheless ensures the creation of a causal relationship between the gesture made and the signal produced. If such a connection is given, a high intimacy, resulting in a high-quality instrument relationship, is created between the player and the guitar. By feeling this immediate feedback, guitar players are able to thoroughly connect with their instrument.

Since its electrification, the electric guitar has been an ongoing research object, subject to significant organologic experimentation and various augmentation efforts. First research ambitions employed analog technology, resulting in various methods of analog signal processing also known as “effects”. Gradually, the focus shifted to digital technology including the use of MIDI and development of digital (multi-) effects. Most recently, electric guitar augmentations have expanded to software and programming environments (Lähdeoja et al. 2010, pp. 41-42).

3.2. Challenges of augmenting electric guitars

There are several challenges associated with augmenting electric guitars. Firstly, as Miranda & Wanderley (2006, pp. 21-22) point out, instrument augmentation consists not only in expanding the sonic possibilities of an instrument but also in maintaining the initial instrument's playing, its sonic and expressive possibilities. Furthermore, existing performance techniques should be taken into consideration when designing new control possibilities (Donovan & McPherson 2014, p. 351).

Another challenge in further augmenting the sonic possibilities of an electric guitar stems from the fact that, just like in the case of an acoustic guitar, both hands of the player are involved in the sound production. With guitarists having their hands full – so to speak – control of all additional sound extensions can only be achieved by resorting to peripheral aspects of guitar playing. This involves exploiting free space that may exist between the hands' playing gestures and/or leveraging the movements of other body parts of the player. Furthermore, augmenting the electric guitar leads to spatial extension, transforming the single instrument into a multitude of interconnected modules making up a playing environment of guitar(s), effects and amp(s) (Lähdeoja 2008, p. 54). A negative consequence of said spatial extension is that along with the increase of sonic possibilities and corresponding control interfaces, playing the instrument gets more and more complex as well, potentially overburdening the musician's capabilities (Lähdeoja et al. 2010, p. 43). In fact, maintaining a player's ability to perform is a major constraint to the extension of sonic possibilities, often resulting in a trade-off between degree of sonic extension and the player's abilities for dynamic control over them (Lähdeoja et al. 2009, p. 327). Cook (2001, p. 1) states that the "spare bandwidth" that players may or not have must always be taken into consideration when designing new musical controllers.

In order to avoid exceeding the physical and mental capabilities of guitar players, most control interfaces for electric guitar have been conceived with simplicity in mind, featuring relatively simple controls and traditionally being conveniently placed within the guitarist's reach (e.g., an effect pedal that is (dis)activated by stepping on it). While this augmentation approach serves its purpose of not overburdening the player, Lähdeoja et al. (2010, p. 43) observe that this practice limits the possibilities for dynamic, real-time interaction with controls which leads to a "sonic stasis common in electric guitar playing: the player chooses a specific sound for a musical part with "on/off" effect switches, playing with the same timbre until the next "monolithic" modification" (Lähdeoja et al. 2010, p. 43). The apparent limitations regarding dynamic and real-time control of guitar effects have also been identified by other researchers in more recent publications:

Konovalovs et al. (2017, p. 354) add that, despite significant technological advances, guitar effects pedals have not changed their original design since their conception. Albeit admitting that effects pedals are easy to use and efficient, they criticize their stationary nature, forcing guitar players to return to their effect pedal board to switch effects on/off or even having to kneel and reach down to change settings. This may hamper the performance quality of the guitar player and negatively affect the show's visual attractiveness.

Hödl & Fitzpatrick (2013, p. 69) discuss the problems of the need to stay in front of the effects pedal board or return to it in order to be able operate effects. Additionally, typical foot-based controllers are highly limited in their actual control possibilities, often only offering push buttons and no gestural or other, more embodied control options.

Kristoffersen & Engum (2018, pp. 352-353) state that while the possibilities *what* can be controlled by guitarists have progressed, the way *how* to control these many musical parameters has not really seen much advancement. Especially among conventional guitar players, floor-based controllers are still the predominant choice – for discrete effect changes as well as expressive controls. They argue however, that using feet for gestural control is actually not a guitar-focused but a universal design concept applicable for all hand-played instruments. By using floor-based controllers, guitarists are almost forced to play two instruments at the same time because "neither the physical construction nor the gestural control of the pedals have any relation to the definition of a guitar" (Kristoffersen & Engum 2018, p. 353).

The research projects outlined here and in Ch. 1 all address the problems and challenges inherent to electric guitars (especially in connection with controlling effects) and augmentations and set out to develop mitigating systems. While they aim (and succeed) to provide guitarists with real-time, and more intuitive effect controls, they do not appear to be well integrated into the typical ecology of guitarists for the reasons outlined in Ch. 1. These shortcomings sparked the idea for this Master's thesis to develop a system that gives more intuitive control over effects while remaining ecologically-valid.

4. Concepts influential to the design of Dextoria

The design of the Dextoria system has been influenced by different scientific concepts relating to music and the design of new musical instruments and controllers. In the following chapters, these concepts are briefly described and, subsequently, their impact on the design decisions regarding Dextoria are highlighted.

4.1. Types of musical gestures

As discussed in Ch. 1, the proposed system will leverage the sound-producing gestures to extend the guitar's sonic control possibilities. Hence, this chapter is dedicated to explaining the types of musical gestures in more detail.

Concerning the functional aspects of musical gestures, Jensenius et al. (2010, under "Functional Aspects of Musical Gestures") summarize and discern the following types:

- Sound-producing gestures
- Sound-facilitating gestures
- Sound-accompanying gestures
- Communicative gestures

Sound-producing gestures can be defined as the gestures that are effectively involved in producing the sound (Jensenius et al. 2010, under "Functional Aspects of Musical Gestures"). Cadoz (1988, p. 7) proceeds to divide the sound-producing gestures into excitation and modification gestures. The excitation gestures induce the vibration of the instrument while the modification gestures modify the way the instrument is vibrating. The workings of two gestures are exemplified when looking at string instruments such as a violin: the violinist induces vibration into a violin string via the bow, the excitation. Subsequently, the left hand of the violinist is used to modify the vibrating string by altering the string length. Nevertheless, excitation and modification gestures cannot be wholly separated: for instance, certain features of the bowing motion (the excitation gesture) such as speed, pressure or acceleration can also contribute to modifying the sound (Jensenius et al. 2010, under "Functional Aspects of Musical Gestures").

Sound-facilitating gestures include different musical gestures that do not directly serve sound production but are nevertheless involved during music performances. For instance, the movement of playing a key on a piano consists not only of the finger actively playing but also correlated hand, arm and upper body movements that support (and influence) the sound-producing gestures of the finger (Jensenius et al. 2010, under "Functional Aspects of Musical Gestures").

Sound-accompanying gestures, in comparison, are not at all part of the sound-production, neither directly nor indirectly. Instead, these movements follow the sound and its features with dancing being the most notable kind of sound-accompanying gesture. Lastly, as the name suggests, communicative gestures are gestures primarily associated with being communicative. These gestures include communication between performers as well as between performers and audience (Jensenius et al. 2010, under "Functional Aspects of Musical Gestures").

One of the main goals of the Dextoria system is to integrate into the conventional playing techniques of guitarists and to extend sonic control possibilities without interfering with or hampering the guitarist’s ability to play. Hence, Dextoria is restricted to making use of sound-producing gestures only. These gestures would be performed by guitarists anyways and thus, it is ensured that the sonic extension happens in a non-invasive manner and does not impair the usual playability of the electric guitar. The system makes use of both variations of the sound-producing gestures: the right-hand setup will use the excitation movements of the strumming/picking hand while the left-hand setup will analyze the movements of modification gestures performed by the fretting hand.

4.2. Intimacy

Another important design concept for Dextoria is intimacy. Fels (2004, p. 672) states that creating new interfaces to control music is one thing while succeeding in developing these new devices to allow for musical expression is another. In this context, “musical expression” happens when players get the possibility to intentionally express themselves through playing/controlling an instrument. If intimacy between the player and the instrument can be achieved, a musical relationship can be created (Fels 2004, p. 672). Intimacy was first introduced by Moore who used the term “control intimacy” to describe “the match between the variety of musically desirable sounds produced and the psychophysiological capabilities of a practiced performer” (Moore 1988, p. 21). Fels (2004, p. 676) defines intimacy in general as “the perceived match between the behavior of a device and the operation of that device”. If a high degree of intimacy is achieved, the player embodies the instrument with the latter becoming an extension of the player, allowing a direct relationship between the player’s intention and the resulting sound. Typically, high intimacy must be developed over time. For instance, when musicians learn new instruments, they become more intimate as they progress (Fels 2004, p. 672).

An example of a recent electric guitar augmentation involving the notion of intimacy is the project “The Whammy Bar as a Digital Effect Controller” by Kristoffersen & Engum (2018). As the whammy bar is a typical feature of an electric guitar, the authors argued that players will be familiar with it and its control mechanism. Consequently, a high level of intimacy with a digitally enhanced whammy bar is likely.

The Dextoria system takes the same line and tries to make use of the untapped potential of another set of well-known gestures, namely the sound-producing gestures. The movements of the strumming/picking hand and the movements of the fretting hand are innate gestures of guitar playing and therefore familiar to all guitar players. The Dextoria system further leverages these gestures and uses them to control guitar effects. As these gestures are very familiar to players, it is consequently likely that a high degree of intimacy can be achieved in a relatively short amount of learning time, allowing for intuitive and expressive control of effects. This feature makes the Dextoria system stand out compared to several other electric guitar augmentation efforts found (see Ch. 1) that require guitarists to learn new, unfamiliar movements to extend sonic possibilities, thus adding another layer of complexity.

5. Basic functionality of Dextoria's setups

Before diving into the detailed, technical description of Dextoria, this chapter gives an overview of the basic functionality of the two setups that make up the system, one for the left hand and one for the right hand.

5.1. Basic functionality left-hand setup

Briefly summed up, the left-hand setup provides guitar players with the possibility to switch between two FX loops according to the position of the fretting hand along the neck of the guitar.

The left-hand setup consists of two components, shown in Fig.s 1 and 2.

1. The "Scout"
   - Clipped to the guitar's headstock
   - Tracks the movements of the fretting hand

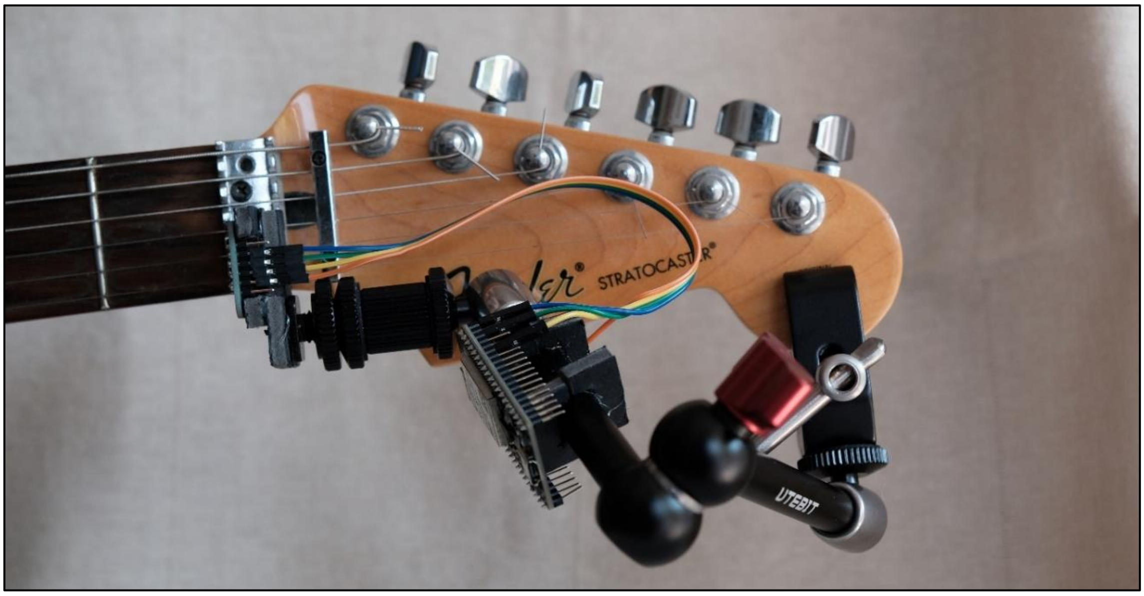

Figure 1 Photo of the Scout (Photo by author).

2. "The Mothership"
   - On the floor like an effects pedal
   - Switches between the two FX loops

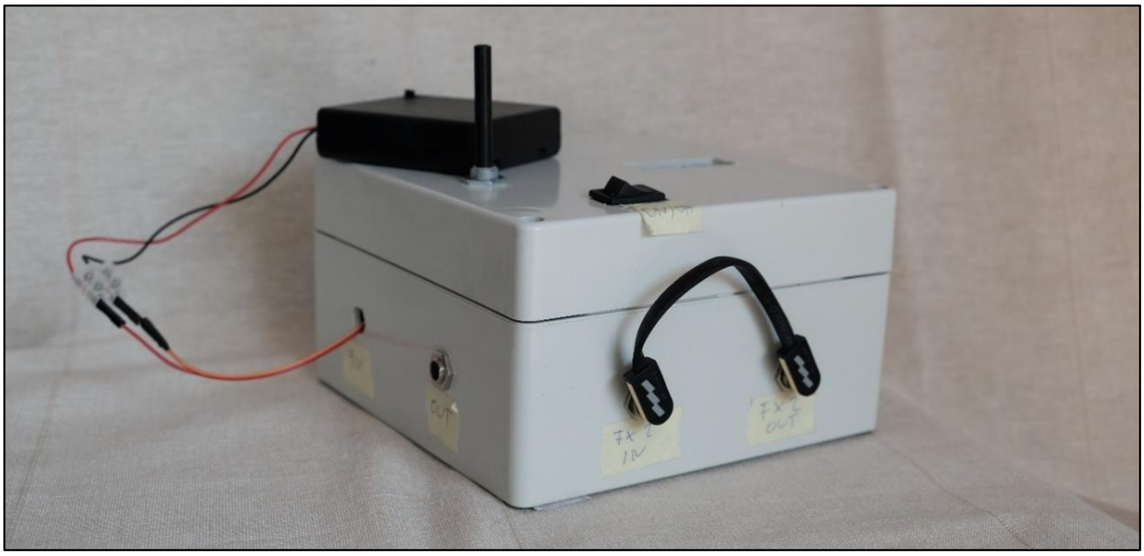

Figure 2 Photo of the Mothership (Photo by author).

A sensor on the Scout determines the current and previous fret positions of the fretting hand. At the same time, a fret threshold can be set by players: under the threshold, FX loop #1 is turned ON (and FX loop #2 turned OFF); over the threshold, FX loop #2 is turned ON (and FX loop #1 turned OFF). The fret threshold can be set to frets 1 to 9 via a potentiometer and is displayed on an OLED display on the Mothership. The Mothership splits the incoming guitar signal into two FX loops and decides which loop to engage based on the data it receives wirelessly from the Scout and the fret threshold set by the guitarist. The left-hand setup is conceived to work alongside all off-the-shelf guitar effects pedals and guitarists have the possibility to individually customize their signal chain according to their needs. Effects pedals can not only be inserted into both FX loops but can also be placed before or after the Mothership in order to be unaffected by an FX loop switch as illustrated in Fig. 3 below.

Figure 3 Possible effects loop constellations A), B), C) and D) of Mothership (Image by author).

5.2. Basic functionality right-hand setup

The right-hand setup gives guitar players the opportunity to control effects via the expression pedal input with the movements of the strumming/picking hand.

The right-hand setup is also made up of two components, shown in Fig.s 4 and 5.

1. The Expressor
   - Strapped to the back of the strumming/picking hand
   - Tracks the movements of said hand

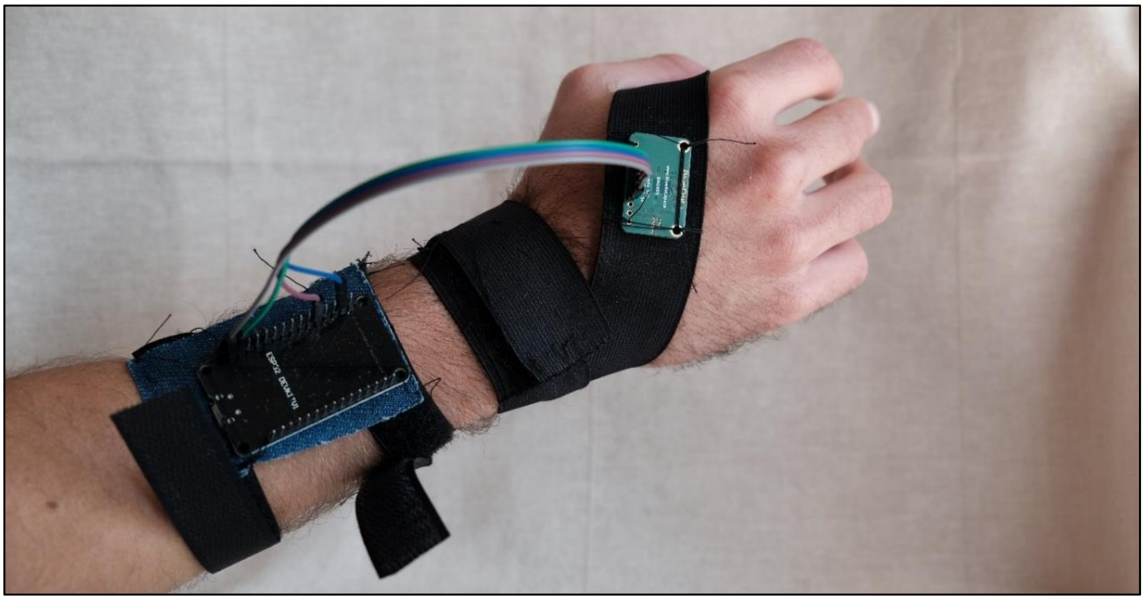

Figure 4 Photo of Expressor (Photo by author).

2. The Expressionist
    - On the floor like an effects pedal
    - Controls effects via the expression pedal input

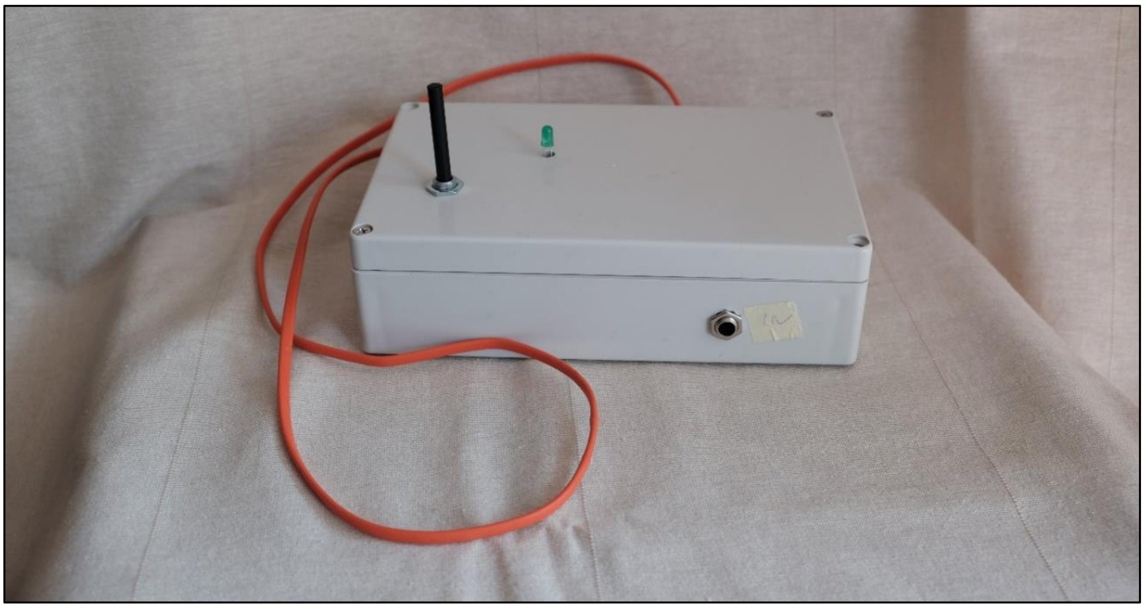

Figure 5 Photo of Expressionist (Photo by author).

A sensor on the Expressor captures the movements of the right-hand by measuring its orientation and acceleration. The Expressionist receives the data sent wirelessly from the Expressor. The player determines whether orientation or acceleration data should be applied for effects control via a potentiometer on the Expressionist. The latter then uses the selected data to control guitar effects pedals via the expression pedal input. Thus, guitar effects pedals that come with the possibility to be controlled via an expression pedal can be used in conjuncture with the right-hand setup.

5.3. Research question and design goals

As outlined in Ch. 1, the main research hypothesis of this Master's thesis reads as follows:

Design and evaluate a sonic control system that:

1. Is ecologically valid in terms of live performance setup
2. Is ecologically valid in terms of conventional playing techniques
3. Relieves guitarists from additional cognitive load associated with controlling guitar effects
4. Enables a smoother and more flexible performance

This hypothesis commands several design goals that must be fulfilled in order for the Dextoria system and its setups to fulfill the objectives set.

- The setups must work alongside the majority of existing guitar effects pedals, amplifiers and electric guitar models, without requiring the guitarist to make too many adaptions.
- Furthermore, as the application focus of the two setups will be on live performances, the products must be "suited for the road". They should be lightweight, easy and safe to transport and sufficiently sturdy to handle the conditions of a live gig. Additionally, they must be capable of working reliably for the duration of a gig. This includes general functionality as well as battery life.
- The setups should not interfere (too much) with conventional playing techniques using the sound-producing gestures of the hands only, thus providing guitarists with intuitive control.

5.4. Video demonstrations

To better convey the capabilities of the Dextoria system and its setups, two short demonstration videos were made. One video shows the left-hand setup working together with various constellations of effects pedals. The other depicts the right-hand setup controlling different kinds of effects pedals, using the two kinds of possible data settings. The two videos were uploaded alongside the Master's thesis to the Phaidra archive of the Kunstuniversität Graz. The following links, which can also be found in the Abstract, lead to the two demonstration videos of Dextoria:

https://phaidra.kug.ac.at/o:130874

https://phaidra.kug.ac.at/o:130875

6. Ecology of guitarists

The goal of this Master's thesis is to develop a system that is ecologically valid and hence can be integrated into the environment of guitarists. Therefore, the "ecology of guitarists" and its features must be explored. This chapter explores typical (live) guitar setups and their signal chains and playing techniques. The findings are initially based on literature and analyses of online sales rankings. Subsequently, the findings are complemented by the results of the interviews regarding the ecology of guitarists. For the empirical study's methodology as well as a complete and detailed listing of the results see Ch. 8 "Empirical study" and Ch. 9 "Empirical findings".

6.1. Typical live guitar setups

In the case of the electric guitar, different modules are combined to create an electro-acoustic chain that is made up of guitarists and their instrument, a variety of analog and digital effects modules and an amplifier (Lähdeoja et al. 2010, p. 39). Naturally, a wide variety of electric guitar models, effects modules and amplifiers are available on the market and used by guitarists. In order to better establish which signal chain components are most commonly found in the ecology of guitarists, the best-seller lists 2022 from reverb.com were consulted. Reverb is the largest online marketplace for buying and selling an ample variety of musical instruments and gear (Reverb LLC n.d.). Next to the marketplace, "Reverb has created an online destination where the global music community can connect over the perfect piece of music gear" (Reverb LLC n.d.). Every year, they review their operations and take stock of the year's best-selling gear.

6.1.1. Electric guitars

Firstly, the starting point of the signal chain will be analyzed, namely the electric guitar. According to Reverb (2022a), the best-selling electric guitars of 2022 are as follows:

Rank	Guitar model
1	PRS SE Silver Sky
2	Fender Player Stratocaster
3	Fender American Professional II Stratocaster
4	PRS Silver Sky John Mayer Signature
5	Fender Player Telecaster
6	Gibson Les Paul Standard '60s
7	Gibson Les Paul Standard '50s
8	Fender American Professional II Telecaster
9	Squier Affinity Telecaster
10	PRS SE Custom 24
11	Gibson Les Paul Classic
12	ESP-LTD EC-1000
13	Squier Classic Vibe '50s Telecaster
14	Squier Classic Vibe '60s Jazzmaster
15	Squier Affinity Series Stratocaster
16	Squier J Mascis Jazzmaster
17	Fender American Standard Stratocaster
18	Squier Paranormal Baritone Cabronita Telecaster
19	Fender American Standard Stratocaster
20	PRS CE 24

Table 1 Best-selling electric guitars of 2022 (Reverb).

As can be seen in Tab. 1, Fender and Fender-type guitars are the dominant guitar choices. Note that Squier is the low-budget brand of Fender and makes identical guitar models (at least in shape) at a lower price tag. Similarly, the PRS SE Silver Sky (ranked first) and the PRS Silver Sky John Mayer Signature (ranked fourth) are also modeled after a Fender Stratocaster but feature a different shape of headstock that appears to be more closely related to a Gibson-type headstock. Within Fender guitars, the Stratocaster model as well as the Telecaster model are predominant. The manufacturer Gibson is also a strong contestant, especially its Les Paul model. The ESP-LTD EC-1000 is also modeled after a Gibson Les Paul, but ESP is an independent company.

The implications for the design of the Dextoria system are as follows. In order to ensure integrability in as many guitarists' setups as possible, it should work with Fender Stratocaster and Telecaster as well as Gibson Les Paul guitars, as well as any other guitars from different brands that are modeled after these.

The headstock design of the mentioned electric guitar models is of special importance as the Scout of the left-hand setup has to be fitted onto the headstock. As will be explained Ch. 7.3.1., the Scout was specifically designed to fit on a variety of headstocks especially those of Fender and Gibson.

The empirical study confirmed the information obtained from Reverb. Of the nine guitarists interviewed, four played a Fender Stratocaster during the interviews, three played a Fender Telecaster, one played an ESP LTD which features a Gibson-type headstock, and one played a special guitar whose brand is unknown to the author. As outlined further in Ch. 9.4.1., the Scout surpassed its design goal by fitting not only onto the Fender Stratocaster and Gibson Les Paul/SG-type headstocks but also onto the headstock of all of other brands used by the participating guitarists.

6.1.2. Effects pedals

The effects modules are next in the signal chain. They primarily come in pedal-form in the context of electric guitars. There are many different types of effects to choose from when creating a guitar rig. The best-selling electric effects pedals of 2022 according to Reverb (2022b) are listed in Tab 2. below:

Rank	Effect model	Effect type
1	Hologram Electronics Microcosm	Sampling and delay multi-effect
2	Keeley Compressor Plus	Compressor
3	EarthQuaker Devices Plumes	Overdrive
4	Line 6 HX Stomp	Multi-effects pedal
5	Proco Rat 2	Distortion
6	Strymon Iridium	Amp & IR cab simulator
7	Boss DS-1 Distortion	Distortion
8	Boss TU-3 Chromatic Tuner	Tuner
9	DigiTech Drop [Pitch shifter]	Pitch shifter
10	Boss BD-2 Blues Driver	Overdrive
11	MXR M169 Carbon Copy Analog Delay	Delay
12	Chase Bliss Habit	Delay/looper
13	Strymon Big Sky Reverb	Reverb
14	JHS Morning Glory V4	Overdrive/boost
15	Strymon Timeline Delay	Delay
16	TC Electronic Ditto Looper	Looper
17	Dunlop CryBaby Wah GCB-95	Wah-Wah
18	Strymon Flint Reverb and Tremolo V1	Reverb/tremolo
19	Boss SD-1 Super Overdrive	Overdrive
20	Ibanez TS9 Tubescreamer	Overdrive

Table 2 Best-selling electric effects pedals of 2022 (Reverb).

For this analysis, the actual brand and name of the listed effects pedals are less important than the kind of effect they produce. Consequently, the effect type has been added after each pedal in the list. Overdrive appears to be among the most bought effects along with delay, distortion, and reverb. Additional effects include looper, tremolo, pitch shifter, compressor, tuner, and amp & IR simulation. Moreover, one multi-effect pedal is on the list. Of the 20 effects pedals ranked, seven come with an expression pedal input. These pedals are the Hologram Electronics Microcosm, the Line 6 HX Stomp, the Strymon Big Sky Reverb, the Chase Bliss Audio Habit, the Strymon Flint Reverb and Tremolo V1, the Strymon Iridium and the Strymon Timeline Delay (Hologram Electronics LLC n.d.; Yamaha Guitar Group Inc. n.d.; Strymon n.d.a; Chase Bliss Audio n.d.; Strymon n.d.b; n.d.c; n.d.d).

The results of the practical study basically mirror the above-mentioned findings: In summary, the participating guitarists tend to use a great variety of effects pedals with the most frequently mentioned ones largely corresponding to the lists above. Apart from commonly used effects such as overdrive, booster, tuner, delay, reverb or Wah-Wah for example, some guitarists also mentioned non-standard effects such as an organ emulator or a Talk Box. Regarding effects units with expression pedal input, the study revealed that out of the participating guitarists most did have at least one effect pedal with expression pedal input albeit not all use it actively in their live setups. For a full list of the effects pedal results of the study see Ch. 9.

As far as the implications for the design of the Dextoria system are concerned, it is evident that the typical ecology of guitarists includes an ample number of effects pedals. Consequently, it is important that the Dextoria system is compatible with this wide array of effects pedals to ensure its integrability into the ecology of guitarists. As already mentioned, the left-hand setup (Scout + Mothership) of the Dextoria system can be used in conjuncture with all guitar effects in various constellations. The right-hand setup (Expressor + Expressionist) can be used in conjuncture with pedals with expression pedal input. The practical findings show that guitarists often have at least one effect pedal with expression input which allows the right-hand setup to be integrated as well.

6.1.3. Amplifiers

Typically, the last component of the electric guitar signal chain is an amplifier. Although Reverb (2022b) has also issued a list of best-selling amps of 2022, it is not really necessary for this thesis to include the different amp models bought the most by contemporary guitarists. The reason for this is that the Dextoria system focuses on what is happening with the guitar signal before it comes to the amplifier and therefore it basically works with any kind of amplifier. It is much more important to stress that guitar players still use amps and renounce using computers in their live setup, which was confirmed in the empirical study. The interviews revealed that all participants use guitar amplifiers as their last element of the signal chain with only one participant stating that he would go directly into a PA system if using an amplifier was not an option.

6.1.4. Lack of computers

In Ch. 1, it was argued that recent guitar augmentations seem to rely on a computer and/or are restricted to specifically programmed effects. This analysis, however, demonstrated that the conventional live guitar rig consists of a guitar going through various hardware effects pedals into an amplifier with the usage of computers being very uncommon. In fact, of all nine guitarists taking part in the study, only one stated to frequently use an audio interface and laptop as part of the live performance setup in the context of experimental, improvisational music. With Dextoria working without the need of computers or programmed effects, it is thus more easily integrated into conventional live performance setups of guitarists.

6.2. Typical playing techniques

There are a lot of different playing techniques for the left as well as for the right hand associated with the electric guitar. In principle, the Dextoria system is conceived to work in conjuncture with all playing techniques, aiming to further leverage the natural hand movements to control effects.

6.2.1. Playing techniques left-hand setup

Schmid (2021, pp. 95-97) mentions the following playing techniques of the left-hand: vibrato, legato, bending, sliding, hammer-on/pull-off, double stops, dampening and harmonics. As the Scout component of the left-hand setup sits on the headstock of the guitar, its fret detection mechanism does not interfere with any left-hand movements made on the fretboard. Thereby, electric guitarists are able to play all left-hand playing techniques mentioned above. Furthermore, the fret detection mechanism does not take into account which strings are played so guitarists are also free to play all techniques on all strings.

Apart from playing techniques, it must also be evaluated to what extent the left-hand setup fits with the structure of existing songs. The primary idea behind the left-hand setup is to facilitate switching between two different guitar sounds with switching between rhythm and lead guitar sounds being an obvious real-life application. The main advantage of the left-hand setup may at the same time be its main disadvantage: separating the fretboard into two sound regions. This means that in order for the left-hand setup to work as intended, the rhythm guitar parts must be played in the lower regions of the fretboard while the lead guitar parts must be played in the upper regions. Songs that follow this clear distinction work well with the left-hand setup. Fortunately, a lot of basic chord shapes can be played using the first four frets of the guitar (see Fig.s 6-11). As can be seen in the pictures, only the Eb major and minor chords cannot be played within the first four frets (see, respectively, Fig.s 6 and 9). Note that for the fret detection, all that matters is the finger closest to the nut of the electric guitar.

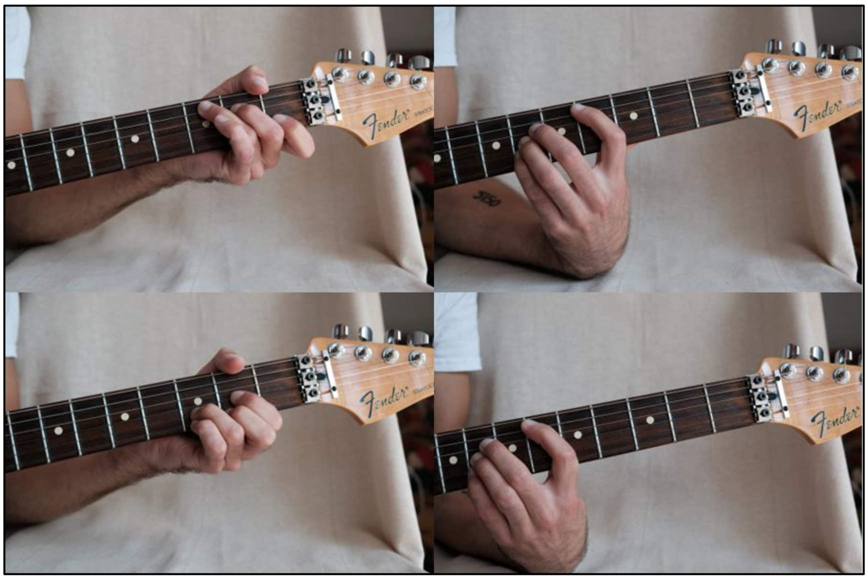

Figure 6 Chord shapes C major, C# major, D major and Eb major (Photo by author).

Figure 7 Chord shapes E major, F major, F# major and G major (Photo by author).

Figure 8 Chord shapes Ab major, A major, Bb major and B major (Photo by author).

Figure 9 Chord shapes C minor, C# minor, D minor and Eb minor (Photo by author).

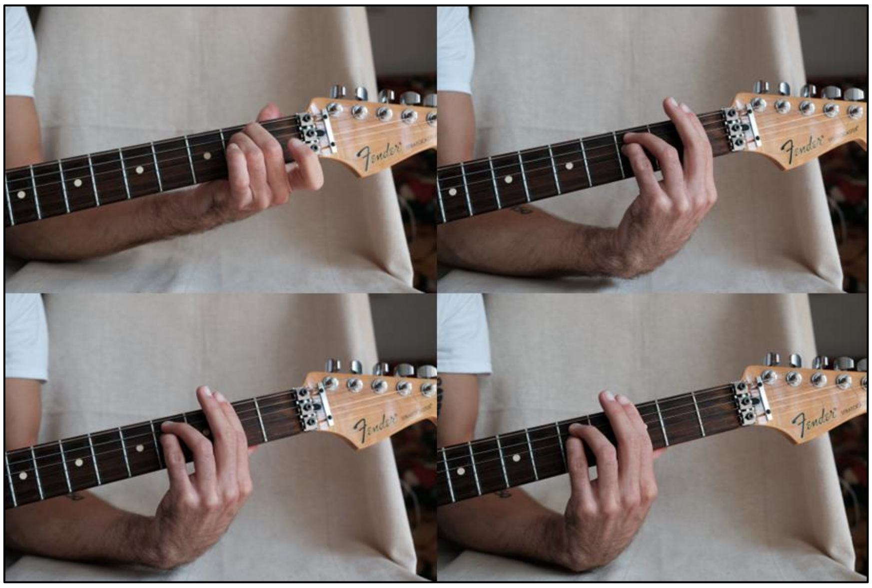

Figure 10 Chord shapes E minor, F minor, F# minor and G minor (Photo by author).

Figure 11 Chord shapes Ab minor, A minor, Bb minor and B minor (Photo by author).

However, there are also songs that use special riffs or chord voicings that result in the rhythm guitar parts being played higher up the fretboard. Then the lead and rhythm guitar parts may overlap as far as fretboard position is concerned and the benefits of the left-hand setup become more of a liability.

6.2.2. Playing techniques of the right-hand setup

As it is the case with the left hand, there are various electric guitar techniques concerning the right hand. Schmid (2021, pp. 97-103) mentions the techniques: finger picking, down picking, alternate picking, sweep picking/sweeping, economy picking, string skipping, hybrid picking/chicken picking, pick slanting, strumming, palm-muting, tapping, tapped/artificial/pinched harmonics, dive bomb. In principle, the right-hand setup is designed to not interfere with any of these techniques. Nevertheless, the empirical study showed that the Expressor wrapped around the back of the right hand led to a reduced ability to palm-mute.

The right-hand setup is really designed to leverage only one technique to control effects, namely strumming. However, the right-hand setup enables players to leverage the different intensities of hand movements required for each technique to control effect parameters. For instance, intense strumming ramps up the value of an effect parameter, while finger picking brings it down again. Thus, effects adapt to the techniques played.

7. Development and documentation of Dextoria

The following part of the Master's thesis is dedicated to documenting the development and current state of Dextoria. Firstly, the ESP32 and the Arduino Integrated Development Environment (IDE) are explained individually as they play a central role in the Dextoria system. Subsequently, the left- and right-hand setups of Dextoria are described in more technical detail with documentation divided into hardware and software parts.

7.1. The ESP32

The ESP32 is the main microcontroller of choice for this project, handling all software tasks necessary for the system to perform. Altogether, the system employs four ESP32s with two being used for the left-hand and the other two for the right-hand setup.

The ESP32 is a chip developed and manufactured by Espressif Systems, designed for mobile, wearable electronics and Internet-of-Things (IoT) applications (Espressif Systems 2023, p. 8). While different options of microcontrollers were tested over the course of the project's duration, including several Arduino-made boards, the ESP32 comes with many qualities that make it an ideal solution for this project. As it is designed for mobile applications, it comes with a very low power consumption. The main reasons why it was selected for this project, however, are its 2.4 GHz Wi-Fi and Bluetooth capabilities, making wireless communication among ESP32s possible. Additionally, it features 34 programmable GPIOs, SPI and I^2C capabilities, all qualities that further emphasize its suitability for the project (Espressif Systems 2023, pp. 8, 34, 37-39). Furthermore, it is inexpensive and compatible with the Arduino "programming language" and can thus be programmed within the Arduino Integrated Development Environment (IDE). As far as power supply is concerned, the operating voltage of the ESP32 ranges from 2.3 V to 3.6 V with 3.3 V being the recommended voltage (Espressif Systems 2023, p. 21).

Note that strictly speaking, the term "ESP32" refers to the ESP32 chip only. However, the term is often used to refer to development boards featuring an ESP32 chip as well. Such development boards facilitate prototyping and interfacing with the chip. For this project, the ESP32 chip was exclusively used in conjuncture with said development boards so accordingly, in this Master's thesis, the term "ESP32" always refers to ESP32 development boards such as the one depicted in Fig. 12.

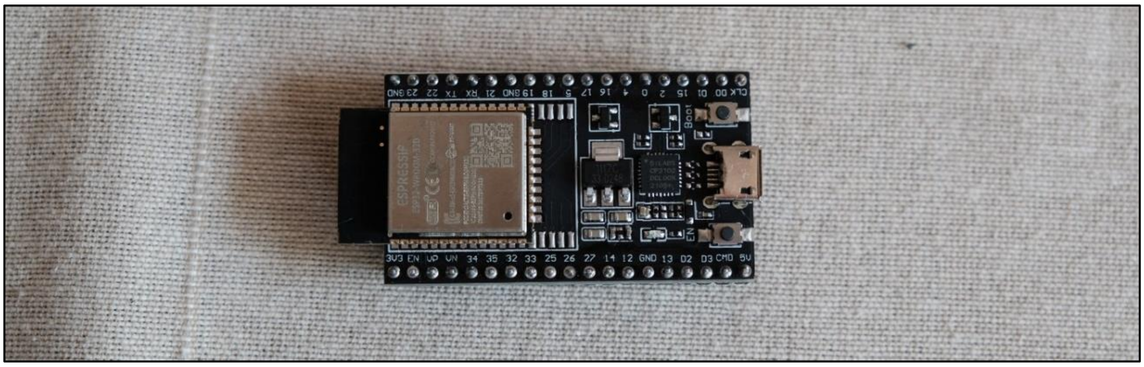

Figure 12 An ESP32 microcontroller (Photo by author).

7.2. The Arduino Integrated Development Environment (IDE)

The Arduino IDE was used to program all codes for this project. Among other features, the platform comes with a text editor for writing code, and it can be connected to microcontrollers to upload programs and communicate with them. It is not restricted to Arduino hardware and, instead, open to third-party boards like the ESP32. Through the Library Manager, external libraries providing additional functionality can be added easily (Arduino n.d.b). The programs are written in the Arduino programming language (Arduino n.d.a).

7.3. Left-hand setup: hardware

The left-hand setup consists of two different hardware components which were named the Scout and the Mothership.

7.3.1. The Scout: hardware

The Scout is attached to the headstock of the guitar and can detect the fret position of the left hand. It comprises an optical time-of-flight (ToF) sensor, an ESP32 microcontroller as well as a custom-made attachment device.

7.3.1.1. The Scout: sensor choice

For the project, several sensors capable of measuring distances were evaluated and tested, including an ultrasonic sensor of the type HC-SR04 and several ToF sensors. Although the ultrasonic sensor was the initial choice, it turned out to be unsuitable for application in this project. It performed reasonably well in detecting the distance of an object featuring a smooth and flat surface, a ruler for example. Unfortunately, it did not function properly with the uneven and changing surface of a human hand playing the guitar. Subsequently, the focus shifted to ToF sensors which proved to be more accurate when dealing with the uneven surface of a hand.

The particular model chosen for this project is a VL531X on a breakout board manufactured by Blue Dot, as shown in Fig. 13.

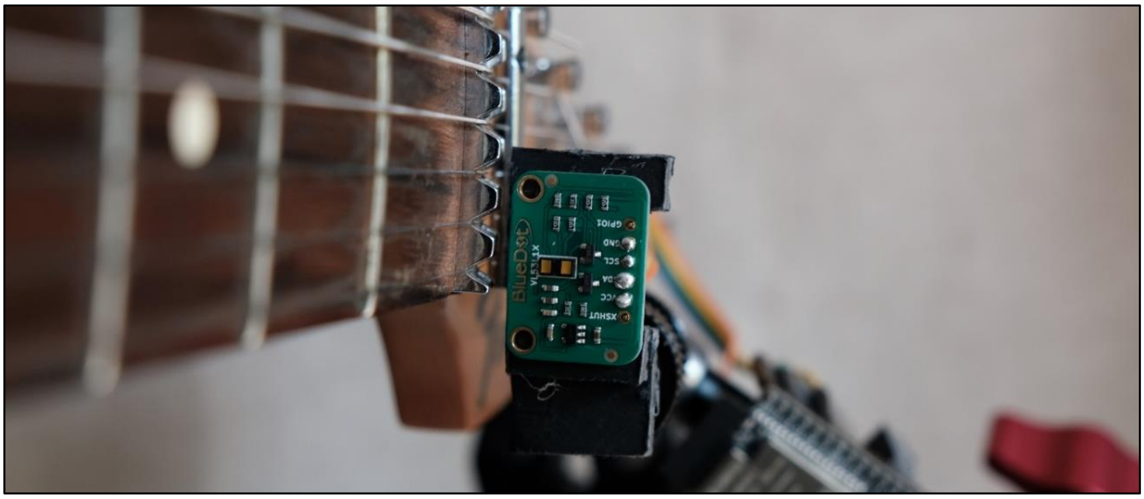

Figure 13 The Blue Dot VL531X sensor used on the Scout (Photo by author).

As the name already suggests, it works with the time-of-flight (ToF) principle. These kinds of sensors emit light rays and measure the distance according to the time passed until the reflected rays reach the sensor again. The rays mentioned are in fact infrared (IR) rays emitted from a Vertical Cavity Surface-Emitting Laser (VCSEL) which features a wavelength of 940 nanometers (nm) – a wavelength outside the spectrum of visible light. Furthermore, the sensors use so-called Single Photon Avalanche Diodes (SPADs). The VL531X was chosen over its competitors because of its sufficient range of up to almost four meters and advanced setup possibilities like narrowing down its region of interest by deactivating the SPADs mentioned above (Ewald 2020).

7.3.1.2. The Scout: sensor positioning and attachment

Naturally, the ideal placement for the sensor as well as the microcontroller had to be established. In this context, the ideal placement is defined as the one position of the sensor on the guitar headstock which gives reliable and useful distance readings of the fretting hand to pinpoint its position along the neck.

This suitable position of the sensor depends very much on the position of the fretting hand while playing the guitar. Thus, it was decided to take photos of the fretting hand while playing in order to determine the right angle of attack for the sensor. Unfortunately, the posture of the fretting hand varies a lot depending on what is played.

Figure 14 Hand posture playing a G chord barre chord shape (Photo by author).

Figure 15 Hand posture playing single notes (Photo by author).

Figure 16 Hand posture playing a G chord (Photo by author).

As can be seen in the pictures, the hand's posture while playing barre chords (Fig. 14) for example is very different from the posture playing single notes (Fig. 15). The barre chord posture gives the sensor a rather large and even angle of attack which makes it easy for the sensor to determine the hand's position. The single note posture, however, gives the sensor a much smaller reflection area which can only be detected in the lower regions of the fretboard. Chords that are not played using a barre chord shape (Fig. 16) also make for a rather uneven reflective surface.

Owing to these inconsistencies, finding the proper sensor position proved to be quite challenging and the attachment devices had to be ameliorated several times before finding the solution currently in use.

Next to the design goal of positioning the sensor in a way that allows accurate fret readings, it was also considered to be most important that the attachment device fits on both Fender, and Gibson-type headstocks. As these two types of headstocks are the most common, it was deemed necessary that the Scout fits onto both types in accordance with the thesis' main goal to provide guitarists with a system that integrates easily into their existing setups.

The current solution consists of a mount, originally designed for cameras and other such devices that was slightly adapted to hold the ToF sensor and ESP32. It can be clamped onto the headstock and, subsequently, adjusted to place the ToF sensor in the right position. While it is flexible enough to fit onto Fender- and Gibson-type headstocks, it is at the same time sturdy enough to maintain its true position while the headstock is moved during performance. Furthermore, it is relatively lightweight, thus keeping the guitar from becoming too top-heavy.

7.3.1.3. The Scout: power supply

The ESP32 draws its power from a small power bank which can be stuck onto the underside of the headstock using Velcro tape. The power bank can be directly connected to the micro-USB port of the ESP32. The ToF sensor is in turn supplied by the 3.3 V output of the ESP32.

7.3.2. The Mothership: hardware

The Mothership is the main hardware unit of the left-hand setup. Its main task is to split the incoming guitar signal into two FX loops and switch between them according to the signals received by the Scout. It is comprised of another ESP32 as well as several small electronic circuits, namely the buffer/splitter, the mixer, and the digital potentiometer. Furthermore, the Mothership features a small OLED display and a potentiometer to set the fret threshold. All its components are housed in a box in the shape of a large effect pedal with a main input jack, send and return jacks for each FX loop as well as a main output jack.

7.3.2.1. The Mothership: audio signal chain

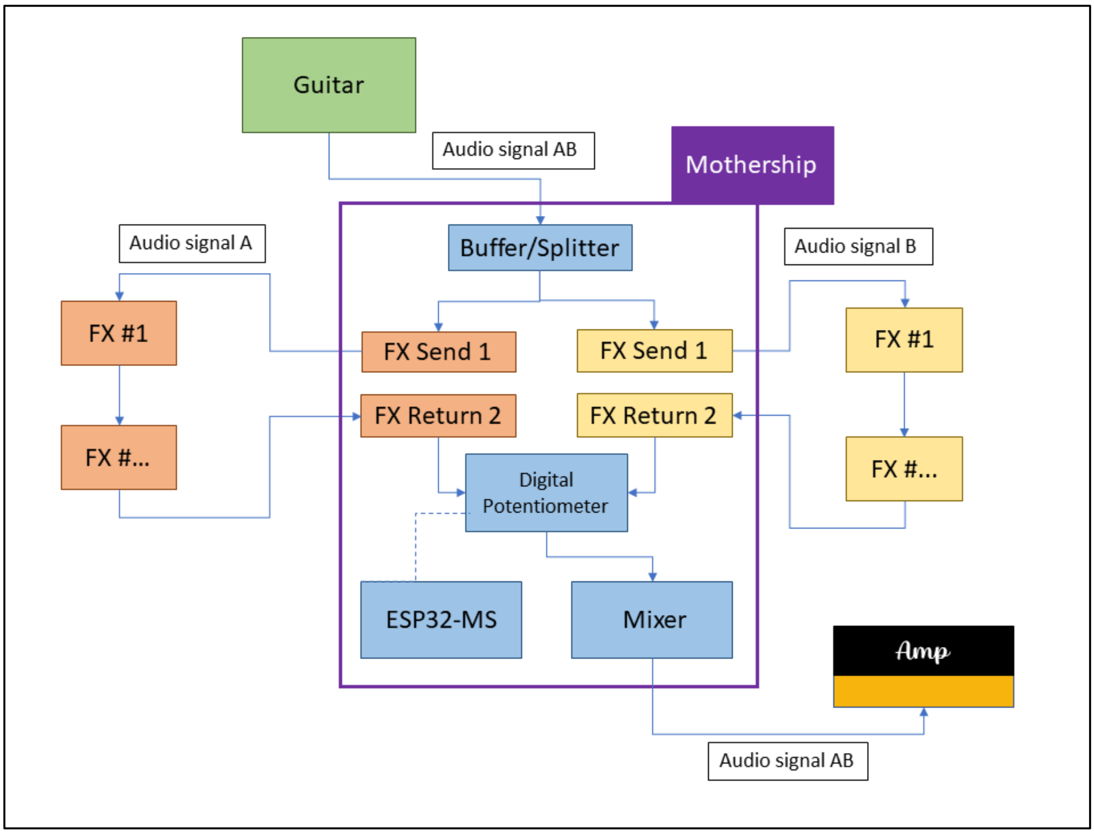

Figure 17 The audio signal chain of the Mothership (Image by author).

Fig. 17 shows the Mothership's audio signal chain and its various components. First of all, the incoming guitar signal is split through a JFET buffer extended to work as a splitter. While the main goal was to split the guitar signal into two distinct signals, having a buffer at the input is an additional advantage since it preserves the higher frequencies in the guitar signal and maintains its strength as it flows through the remaining signal chain without coloring the sound (Pete n.d.).

For this project, a circuit schematic conceived by Jack Orman (2007) was used. As already mentioned, it takes the circuit of a JFET buffer and extends it to work as a splitter, as shown in Fig. 18.

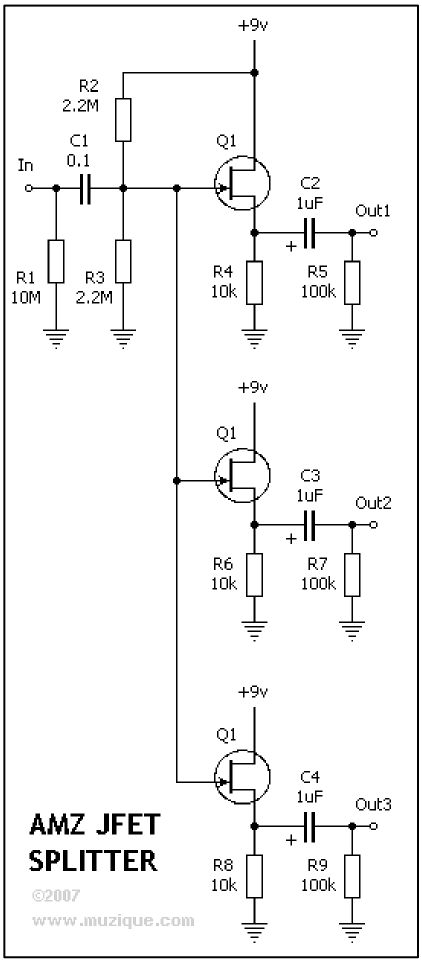

Figure 18 Schematic of buffer/splitter (Screenshot by Author).

In this example circuit, the signal can be split into three output signals. However, as this project only requires two separate signals, the circuit was slightly altered to fit these requirements. For this project J201 transistors were utilized – one of many possibilities mentioned in the article. Firstly tested on a breadboard, the parts were then soldered onto a stripboard following the layout found on the article's website. Fig. 19 shows the stripboard layout while Fig. 20 depicts the finished result.

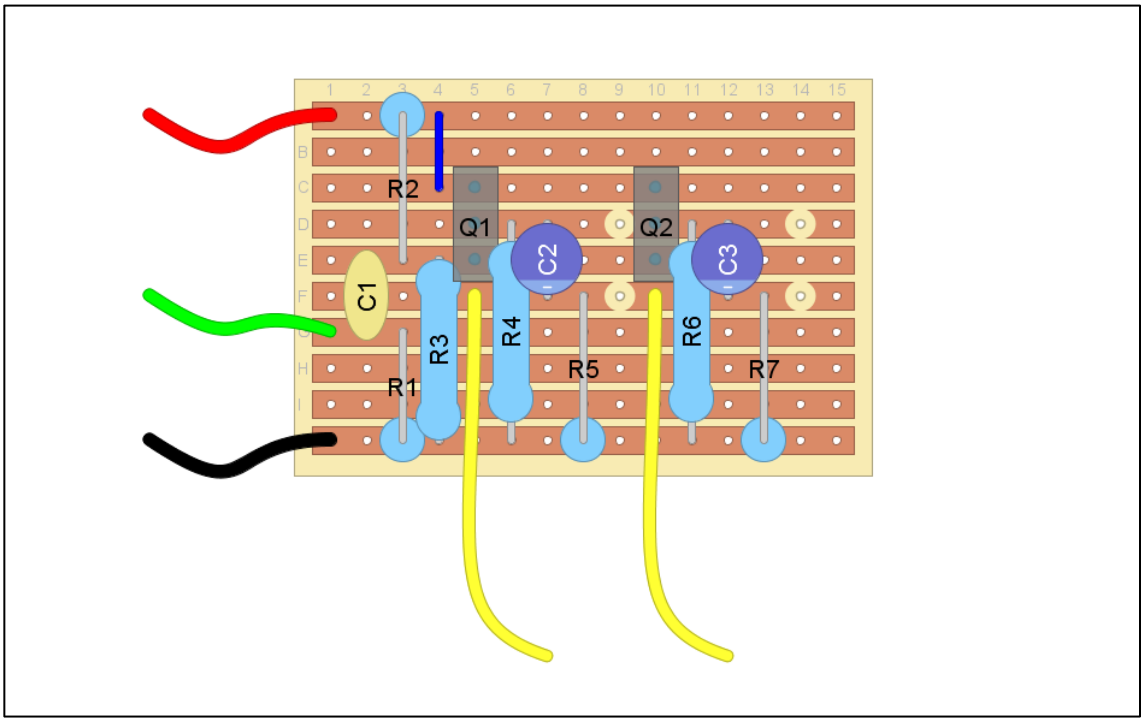

Figure 19 Stripboard layout of the buffer/splitter (Image by author).

The input of the buffer/splitter was then soldered to a 6.3 mm audio jack which serves as the input jack of the Mothership. The two output signals of the buffer/splitter were in turn connected to two audio jacks acting as the FX sends 1 and 2 outputs.

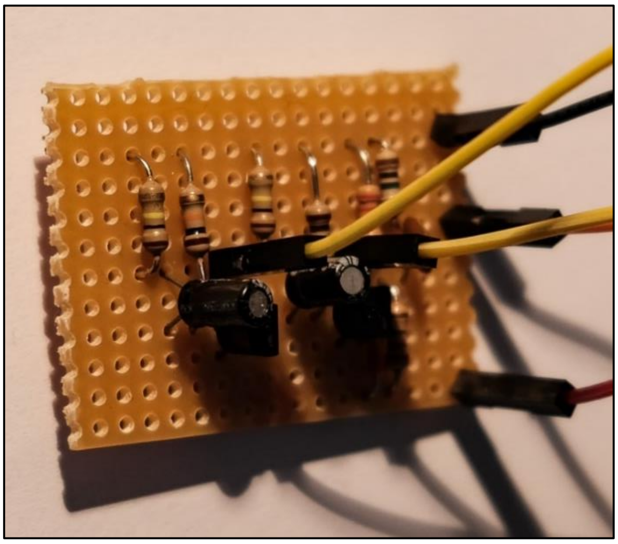

Figure 20 Image of the buffer/splitter (Photo by author).

The two signals are then sent out of the Mothership to their respective FX loops 1 and 2. After going through their effect chains, the signals re-enter the box through another pair of 6.3 mm audio jacks, labelled FX returns 1 and 2. These two jacks are connected to a digital potentiometer which again leads into a mixer that merges the two signals into one output.

Originally, the schematic for the mixer used in this project involved conventional, mechanical potentiometers to control the volume of each FX loop. However, the idea was to switch between the two FX loops according to fret position, thus some kind of volume control which is controllable via an ESP32 was needed. The solution was found in the form of a digital potentiometer. According to Analog Devices they can be defined as follows: “Digital potentiometers are digitally controlled variable resistors that can be used in place of their functionally equivalent mechanical counterparts” (Rice & Creech 2015).

The digital potentiometer of choice for this project is the MCP4251. It offers an 8-bit resistor network resolution, resulting in 257 (0-256) steps and includes two separately controlled potentiometers. It features an operating voltage range from 2.7 V to 5.5 V making it possible to power it via the ESP32’s 3.3 V supply and is controlled via the Serial Peripheral Interface (SPI) (Microchip Technology Inc. 2008, p. 1).

Following instructions from Matthew McMillan’s blog (2014), the MCP4251 was connected to the ESP32 as follows:

- MOSI/SDI – GPIO 23
- MISO/SDO – GPIO 19
- SCK – GPIO 18
- CS – GPIO 5
- Shutdown pin – GPIO 4 (digital) and a 4.7k Ohm pull down resistor to ground
- V_{ss} – 3.3 V of ESP32 circuit
- V_{dd} – Ground of ESP32 circuit
- WP – 3.3 V of ESP32 circuit
- P0B – Ground of audio signal circuit
- P0A – 9 V of audio signal circuit
- P0W – Audio signal FX loop 1
- P1B – Ground of audio signal circuit
- P1A – 9 V of audio signal circuit

- P1W – Audio signal FX loop 2

Fig. 21 below shows the connections of the MCP4251 as shown in its datasheet.

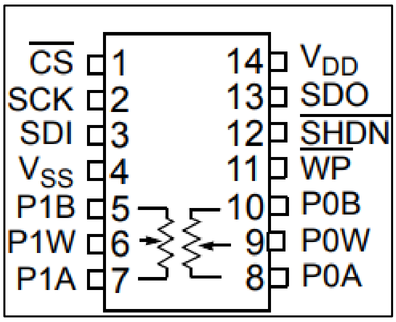

Figure 21 MCP4251 connections I (Screenshot by author).

Like the buffer/splitter, the circuit was tested on a breadboard and subsequently soldered onto a stripboard. As already touched upon, the MCP4251 in conjuncture with the ESP32 replaces the mechanical potentiometers' task of adjusting the volume of each FX loop.

After adjustment, the two signals are sent to the mixer which merges them into one output signal sent to the guitar amplifier. To build the mixer, schematics of the "Mini Mixer" from General Guitar Gadgets (2016) were used. The original schematics involve the possibility to merge four signals. With only two being used in this project, the schematic was adapted to fit the project's needs. As always, the circuit was first modeled on a breadboard and subsequently soldered onto a stripboard. Fig. 22 shows the stripboard layout of the mixer while Fig. 23 depicts the finished result.

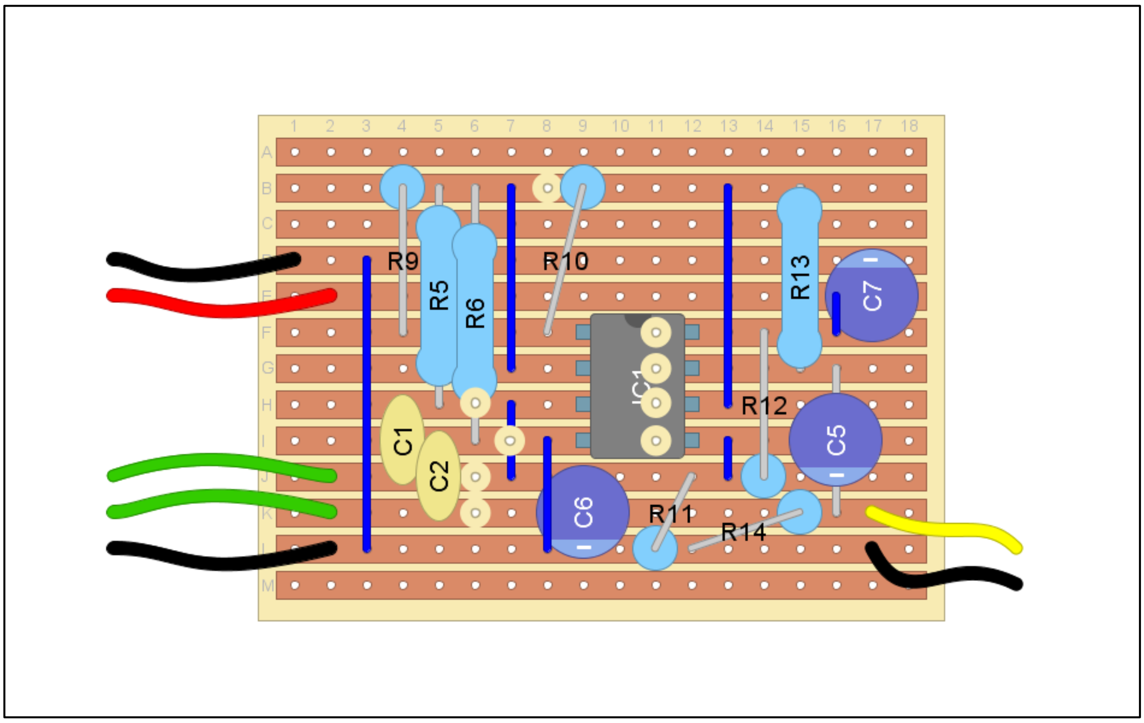

Figure 22 Stripboard layout of the mixer (Image by author).

The sole output of the mixer was soldered to a 6.3 mm audio jack serving as the output jack of the Mothership and leading the signal to the guitar amplifier (or connecting it to other guitar effects pedals positioned after the Mothership).

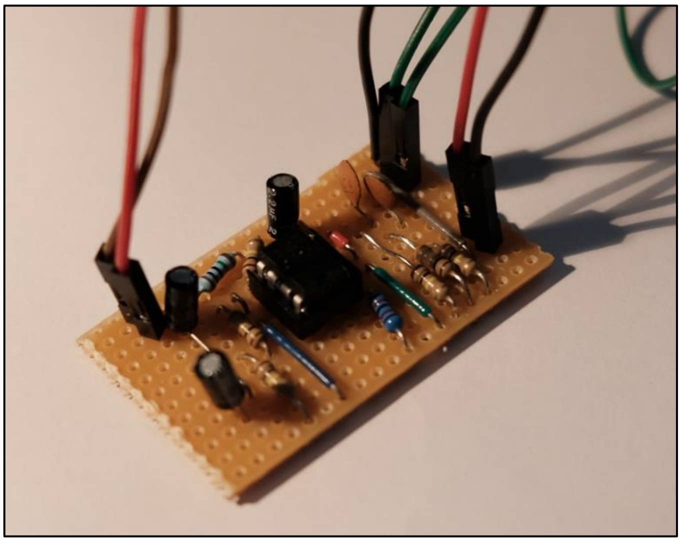

Figure 23 Image of the mixer (Photo by author).

7.3.2.2. The Mothership: other components

Apart from the components concerned with audio processing, the Mothership also features an OLED display and a mechanical potentiometer. These two elements allow the user to set the fret threshold that determines at which fret the two FX loops are switched. The mechanical potentiometer features a resistance of 10k Ohms and has a linear track. The latter was deemed to be a better solution than a logarithmic functionality as it is not used as a volume control but to set specific, equally distanced values (Coates n.d.). The potentiometer is connected to the stripboard containing the digital potentiometer for 3.3 V power and Ground and connected to GPIO 32 on the ESP32.

In order to convey to the user which fret is currently set as threshold, it was decided to add a small OLED display, thus increasing the usability of the Mothership. OLED stands for Organic Light Emitting Diodes and is a flat light emitting technology. OLEDs consist of a series of thin, organic films placed between two conductors that emit light if an electrical current is applied (Mertens 2006). While an LCD, or Liquid Crystal Display has also been considered, the OLED was chosen in the end because it comes with several advantages over LCD including:

- Improved image quality providing a better contrast and higher brightness
- Lower power consumption
- Simpler design, enabling ultra-thin, flexible, foldable and transparent displays
- Better durability

Source: Mertens (2006)

These qualities render it an optimal candidate for use in a live performance environment that often comes with dark or dimly lit stages.

For the project, an SSD1306, 128x32 sized display, communicating via I^2C is used. The I^2C version was chosen since it is fairly simple to connect and because the digital potentiometer already occupies the ESP32 pins needed for SPI. It is connected to the I^2C pins of the ESP32 and gets its 3.3 V from the digital potentiometer's stripboard.

7.3.2.3. Mothership: power supply

The Mothership's power supply is two-fold with the ESP32, digital and mechanical potentiometers and OLED display being powered differently than the buffer/splitter and mixer components.

The initial means of power supply for the ESP32 was a conventional power bank which comes with the advantages of being 1) rechargeable and 2) customizable as guitarists can decide themselves which power bank to use. However, the use of power banks is inefficient in conjuncture with the 3.3 V-based ESP32. A power bank supplies 3.7 V that are then transformed into 5 V for the USB standard and must then be reduced to 3.3 V for the ESP32 again, resulting in losses (RadioShuttle Network Protocol n.d.). While this problem would have been tolerated in this case, another problem ruled out the usage of power banks completely: with the ESP32 being in the same box as the audio circuit and therefore really close to the audio circuit, the latter became very noisy due to the power supply of the ESP32. Tests revealed that a battery-based power supply using the VIN pin of the ESP32 instead of its micro-USB port results in significantly less noise pollution of the audio circuit. Hence, the ESP32 is powered by three AA 1.5 V alkaline batteries providing a total of 4.5 V. It subsequently provides power to the digital potentiometer, the mechanical potentiometer determining the fret threshold and the OLED display showing the current fret threshold.

Finding the proper means to power the buffer/splitter as well as the mixer was more straightforward: They both require 9 V to run which is very convenient as most guitar effects pedals operate on the same voltage. The two possibilities of using a standard 9 V battery or 9 V supplied by a Harley Benton pedalboard power distributor were tested with the battery coming out on top due to a less pronounced introduction of noise.

7.3.2.4. The Mothership: housing

All the components that make up the Mothership are housed in a box made from ABS plastic (compare Fig. 24). ABS or Acrylonitrile Butadiene Styrene is a thermoplastic material that combines many beneficial qualities such as toughness, impact-resistance, lightness and low-cost (Habib 2023). The outside dimensions of the Mothership's housing measure 15 x 15 x 6 cm, making it bigger than most conventional guitar effects pedals. However, these dimensions were chosen to safely fit all components into one box. In order to fulfill the project requirements, several adaptations were made to the housing. Firstly, seven holes, measuring 10 cm in diameter, were drilled into the sides of the box to accommodate the six audio jacks needed as well as the power supply. Additionally, one 10-cm-hole was drilled into the lid for the mechanical potentiometer setting the fret threshold. For the power switch, activating the 9V supply for the buffer/splitter and mixer, and the OLED display two holes respectively were drilled and sanded into rectangular openings.

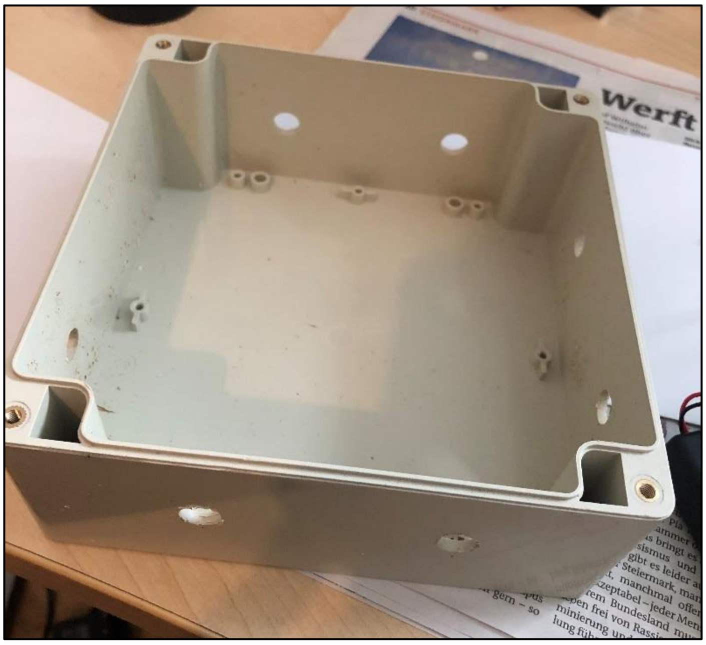

Figure 24 Early image of the housing of the Mothership (Photo by author).

7.4. Left-hand setup: software

With the hardware part of the left-hand setup covered, the next section outlines the development of the software for the left-hand setup. As it was done in the previous chapter, this section will be split into the codes done for the Scout and for the Mothership. Like all codes for this project, the codes for the Scout and the Mothership were written using the Arduino Integrated Development Environment (IDE).

7.4.1. The Scout: code

The code written for the Scout handles the following tasks:

1. Interface with the VL531X ToF sensor
2. Process the distance data gathered
3. Send the processed data to the Mothership

The following flowchart in Fig. 25 depicts the workings of the code. Below the image, the steps are outlined in more detail.

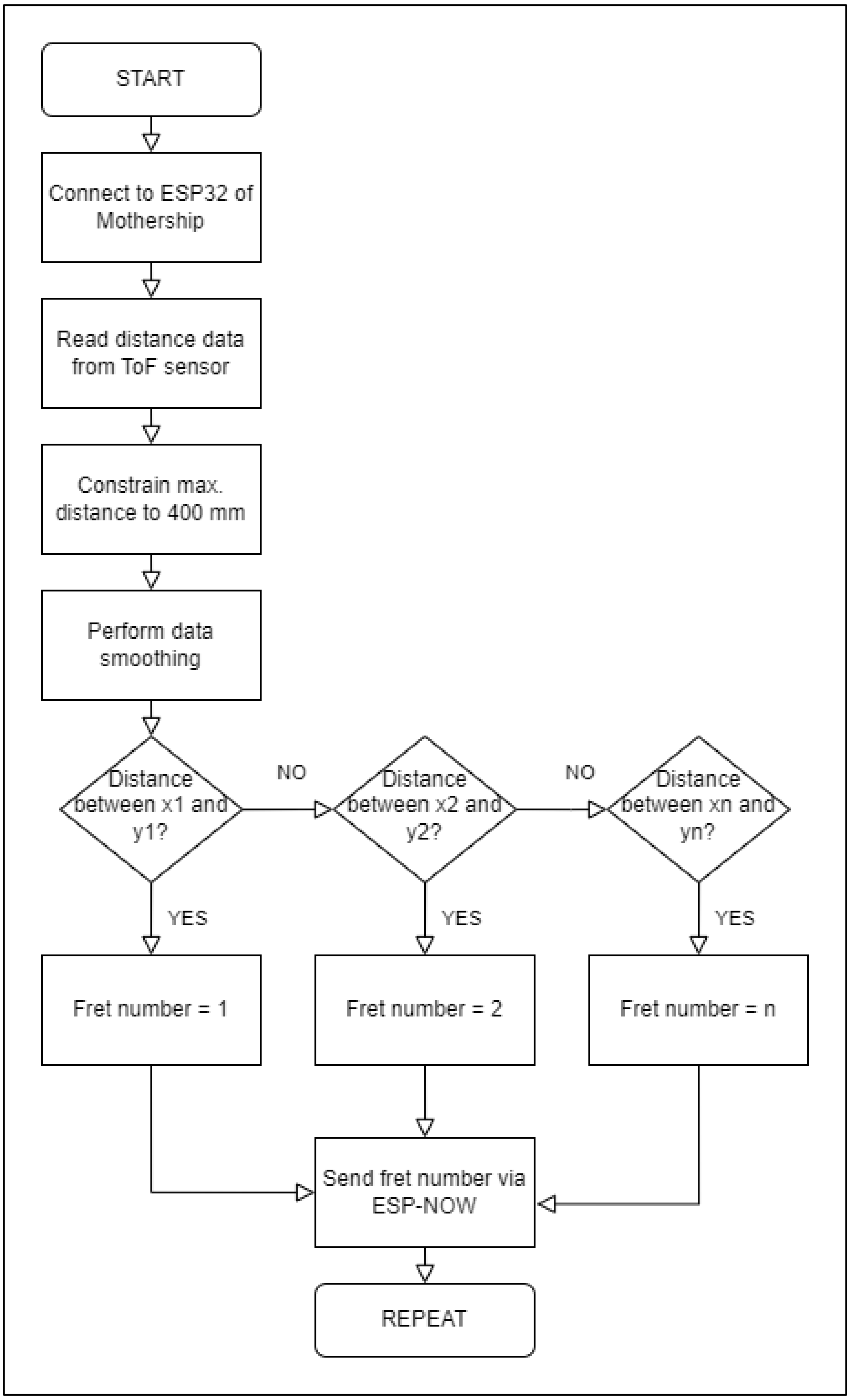

Figure 25 Flowchart depicting the code logic of the Scout (Image by author).

7.4.1.1. The Scout: ToF sensor

The VL531X ToF sensor functions via the I^2C protocol and can be powered by either 3.3 V or 5 V (BlueDot UG n.d.b). As the ESP32 is only capable of supplying 3.3 V, the sensor was connected to the 3.3 V output pin and the ground pin of the microcontroller. The ESP32's standard I^2C pins are GPIO 21 for SDA and GPIO 22 for SCL and connections were made accordingly.

To interface with the sensor, the VL53L1X library for Arduino by Pololu (n.d.) was used. This library facilitates working with the sensor. Thus, functions such as getting sensor readings or altering the sensor's settings can be easily accessed. The sensor is set to medium distance mode, a timing budget of 20 milliseconds and a ROI (region of interest) size of 16x16 SPADs.

7.4.1.2. The Scout: processing data

The sensor reads the distance in mm, constrained to 400 mm as longer distances are not desirable for the intended application. Then, the sensor readings are smoothed a little bit by calculating the average of every 80 samples. This results in more consistent readings.

In order to be able to take absolute distance measurements and assign them to guitar frets the mathematical relationship of the distances between the frets had to be established. The resulting formula (MathIsGreatFun 2017) to calculate the current length of the guitar string depending on the fret is labeled as Eq. 1.

$$L_k = \frac{L_0}{(\sqrt[12]{2})^k}$$

k = fret

L_k = string length at fret k

L_0 = scale length

Equation 1

However, Eq. 1 gives the string length after the finger pressed on the fret or in other words, from the finger/fret all the way to the bridge of the guitar. In order to get the distance from the sensor at the headstock to the finger (and corresponding fret) the result must be subtracted from the total scale length resulting in Eq. 2.

$$D_k = L_0 - (\frac{L_0}{(\sqrt[12]{2})^k})$$

k = fret

D_k = distance from nut to finger/fret

L_0 = scale length

Equation 2

In the last step, Eq. 2 was transformed so that the fret k is expressed depending on the distance measured by the sensor (Eq. 3).

$$k = 12\log_2 \frac{L_0}{D_k - L_0}$$

k = fret

D_k = distance from nut to finger/fret

L_0 = scale length

Equation 3

The next task was to make a sketch that allows the setup to read the distance and then automatically output the correct fret number. As the hand is always nearer to the sensor than the fret, it was determined that certain fret ranges must be defined. The ESP32 must then be able to recognize which distances, coming from the sensor, fall into which fret range and then output the correct fret. Since a guitar player’s fingers are always between the area of two frets, a range of a fret can be defined with the upper value being the fret distance of fret k and the lower value being the fret distance of fret k-1 (compare Fig. 26).

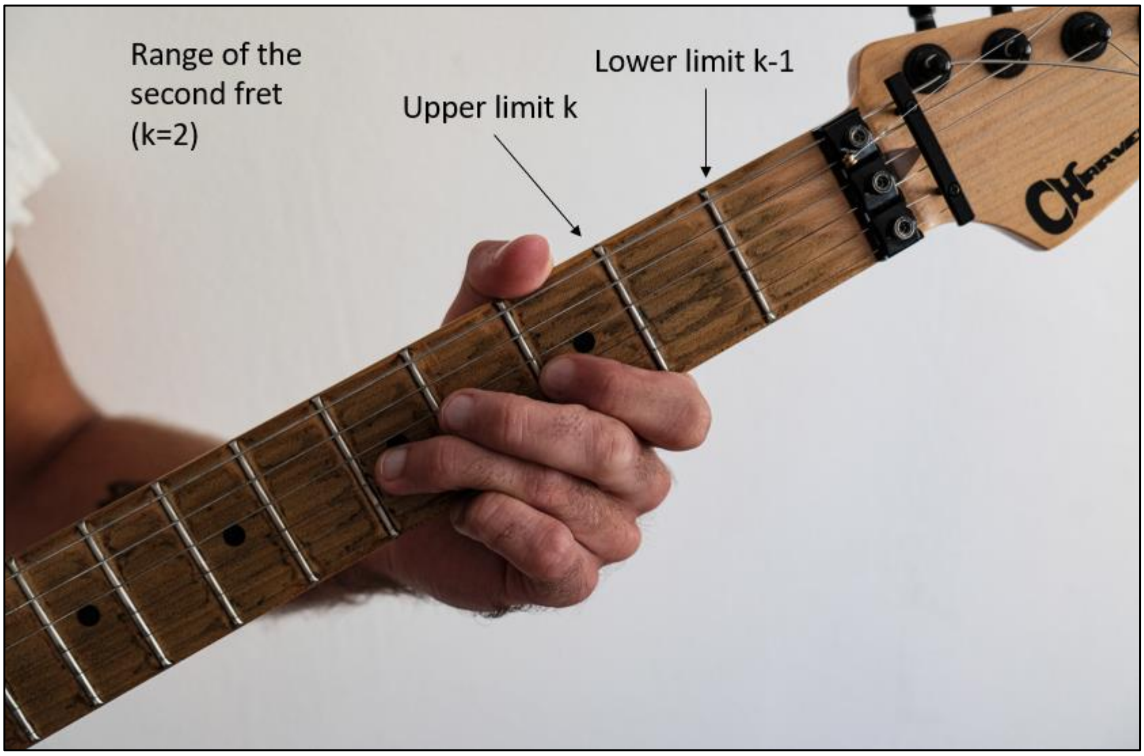

Figure 26 Image highlighting upper and lower limits of fret range (Image by author).

Following this principle, the fret ranges listed in Tab. 3 were defined:

Fret number k	Lower limit [mm]	Upper limit [mm]
0		
1	0	36.4
2	36.4	70.7
3	70.7	103.1
4	103.1	133.7
5	133.7	162.5
6	162.5	189.8
7	189.8	215.5
8	215.5	239.8
9	239.8	262.7
10	262.7	284.3
11	284.3	304.7
12	304.7	324.0
13	324.0	342.2
14	342.2	359.3
15	359.3	375.5
16	375.5	390.8
17	390.8	405.3
18	405.3	418.9
19	418.9	431.8
20	431.8	443.9
21	443.9	455.3
22	455.3	466.2

Table 3 Calculated fret ranges (Table by author).

While these ranges are theoretically evident, it was necessary to manually adjust some values when working with the actual setup. The adjustments were made by experimenting with different values that were added or subtracted to the theoretically calculated upper and lower limits. The final values are shown in Tab. 4. Currently, accurate detecting of frets from one to nine is possible. From the ninth fret onwards, accurate detection becomes increasingly difficult. One possible explanation is that the beam of the ToF sensor gets too broad at such a distance; another is that the beam is reflected by the fretboard itself when reaching the tenth fret.

Fret number k	Lower limit [mm]	Upper limit [mm]
0		
1	8	35
2	35	70
3	70	100
4	100	125
5	125	145
6	145	157
7	157	169
8	169	183
9	183	200
10	200	229
11	220	232
12	232	334
13	334	352
14	352	369
15	369	386

Table 4 Manually adjusted fret ranges (Table by author).

The adjusted ranges were implemented in the code using the if() function that determines which fret range the current sensor reading falls into.

7.4.1.3. The Scout: send data

With the fret detection mechanism working, the next part of the code covers sending the data to the Mothership’s ESP32 to control the two FX loops according to the current fret.

Several different means of data transmission have been tested and evaluated for this project. These include wire-based options such as MIDI via cable and MIDI-USB and wireless options like MIDI BLE (Bluetooth Low Energy) and OSC (Open Sound Control). Of course, wireless options were deemed more desirable for the project and MIDI BLE was the preferred transmission method for a long time for it does not rely on Wi-Fi and a router to work – requirements potentially inappropriate for a live performance/gig environment. However, as communication between two ESP32s (instead of between ESP32 and laptop) became necessary, another means of communication was discovered that proved to be optimal for the project's demands – the ESP-NOW protocol.

According to the Espressif website, ESP-NOW is a wireless communication protocol developed by Espressif, which enables direct, fast, and low-power control of smart devices without needing a router (Espressif Systems n.d.a). Its features include:

- Quick and automatic connectivity once two or more devices have been paired
- Fast transmission speed
- Low power-consumption
- Improved range and reception

  Source: (Espressif Systems 2021)

As already mentioned, these qualities make it ideal for the project.

Using the ESP-NOW library for the Arduino IDE (Espressif Systems n.d.b), the necessary code was added, enabling fret data transmission from the Scout's ESP32 to the one of the Mothership.

7.4.2. The Mothership: code

The code written for the Mothership consists of several parts, handling different tasks:

1. Receive fret data from the Scout
2. Determine selected fret threshold
3. Display selected fret threshold
4. Alter wiper position of digital potentiometer according to fret and threshold information to switch between the two FX loops

The following flowchart in Fig. 27 depicts the workings of the code. Below, the steps are outlined in more detail.

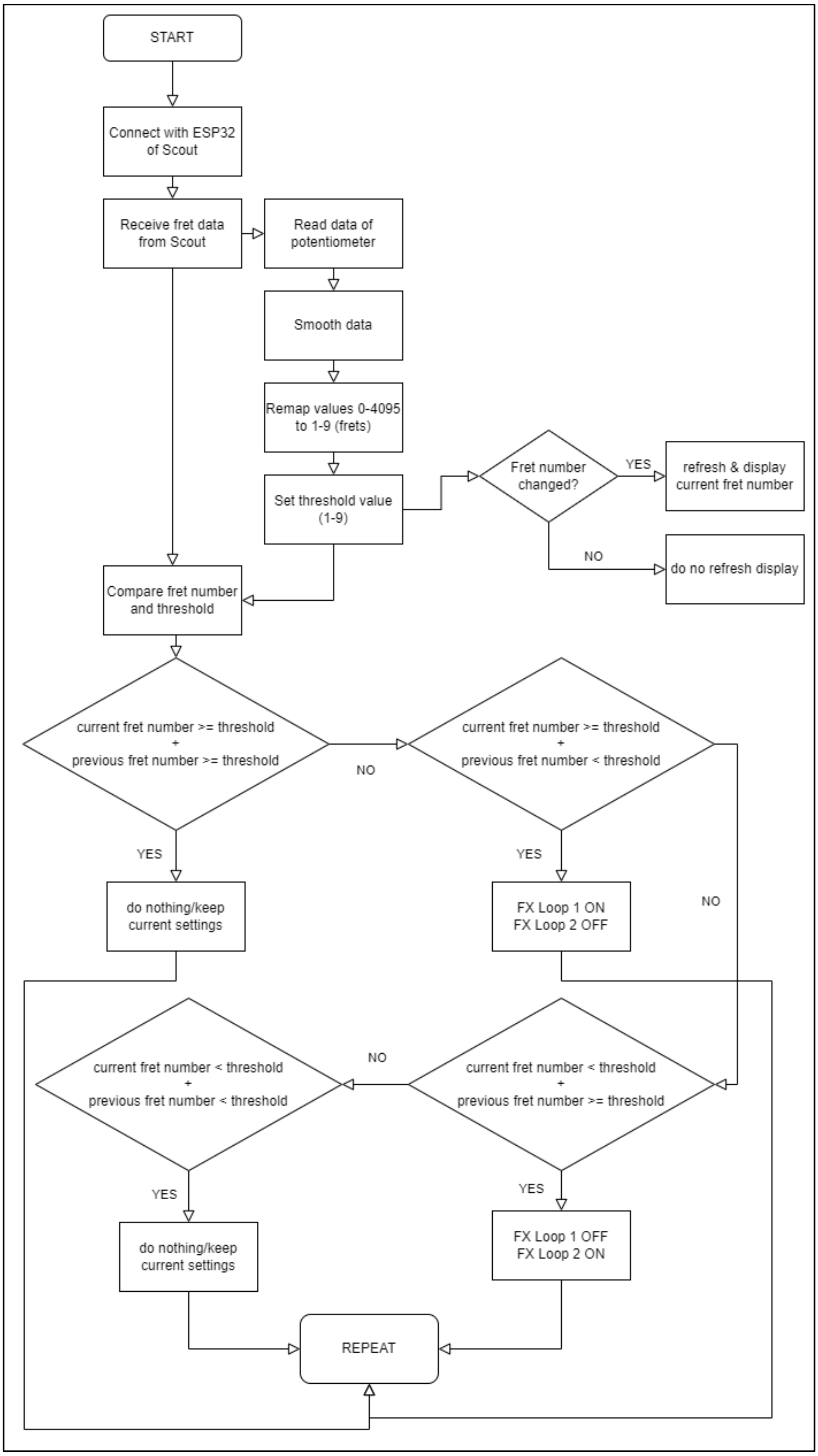

Figure 27 Flowchart depicting the code logic of the Mothership (Image by author).

7.4.2.1. The Mothership: receive data

Firstly, the fret data, sent from the Scout's ESP32 must be received by the Mothership's ESP32. To this end, a code, complimentary to that of the Scout was written using the ESP-NOW library (Espressif Systems n.d.b).

7.4.2.2. The Mothership: determine selected fret threshold

As outlined in Ch. 7.3.2.2., a mechanical potentiometer is used to determine which fret serves as the point separating the two FX loops. This mechanical potentiometer is connected to GPIO 32 of the ESP32, and its values are firstly read before being smoothed by calculating the average over 100 samples. As the potentiometer is meant to determine the fret threshold going from the first fret to the ninth fret, the analog values ranging from 0 to 4095 are remapped to the range from 1 to 9.

7.4.2.3. The Mothership: display selected fret threshold

The selected fret threshold is then displayed on the small OLED display, also mentioned in Ch. 7.3.2.2. The display also works via I^2C and is hence connected to the two standard I^2C GPIOs 21 (SDA) and 22 (SCL) of the Mothership's ESP32. Since it is a SSD1306 OLED display, the Adafruit SSD1306 Arduino library (Fried, Gregg, and Canaday n.d.) in conjuncture with the Adafruit GFX library (Fried n.d.) were used for programming the display. In order to only refresh the display if the fret value is actually altered, an if() function was implemented, comparing the previous fret threshold value with the current one. In this same if() function, the fret threshold variable is updated as well to ensure it is only updated if the potentiometer is actually turned.

7.4.2.4. The Mothership: switching between FX loops

Next, the code of the Mothership performs its main tasks, namely altering the wiper position of the digital potentiometer according to fret and threshold information to switch between the two FX loops.

The MCP4251 digital potentiometer is used for this project. This particular model comes with two potentiometers whose wipers can be set digitally via the ESP32. The MCP4251 works via SPI and next to the standard SPI library, a custom-made library developed by Matthew McMillan (2014) was used to communicate with the potentiometer. In order to switch between the two FX loops the logic outlined in the flowchart (Fig. 27) was applied and implemented using if() functions. In order to turn on FX loop 1, the wiper of the MCP4251 controlling FX loop 1 was set to 255 while the wiper controlling FX loop 2 was set to 0. In order to turn on FX loop 2 and switch off FX loop 1, the process works vice versa.

7.5. Right-hand setup: hardware

The hardware for the right-hand setup is comprised of two components, named the Expressor and the Expressionist.

7.5.1. The Expressor: hardware

The Expressor is the device attached to the hand and arm of the guitarist, capable of capturing the playing and strumming movements of the player’s hand. It consists of an IMU (inertial measurement unit) sensor, an ESP32, a battery case and custom-made textile straps to fix the mentioned parts to the guitarist’s body. In the following, the IMU sensor, attachment straps and power supply are described in more detail.

7.5.1.1. The Expressor: sensor choice

In order to be able to capture the movements made by the guitarist’s strumming hand, it was decided to use an IMU sensor. These types of sensors are capable of measuring motion by detecting linear acceleration as well as angular velocity. The former is measured using accelerometers while the latter is obtained by gyroscopes. Often, such sensors also come with sensor fusion capabilities that, in combination with a magnetometer, combine the raw sensor data from accelerometers and gyroscopes to calculate relatively accurate roll, pitch and yaw data (Harris 2023).

The sensor used for this project is the Bosch BNO055 on a breakout board manufactured by Blue Dot (compare Fig. 28). This sensor contains an accelerometer, a gyroscope and a magnetometer and comes with its own integrated fusion software capable of sensor fusion which means it can not only output raw data but also orientation (roll, pitch and yaw) data (Bosch Sensortec GmbH n.d.). It can work on either 3.3 V or 5 V power and works via I^2C (BlueDot UG n.d.a). Its power and ground pins are connected to the ESP32’s 3.3 V pin and ground pin respectively while the SDA and SCL pins are connected to the ESP32’s standard I^2C pins 21 (SDA) and 22 (SCL).

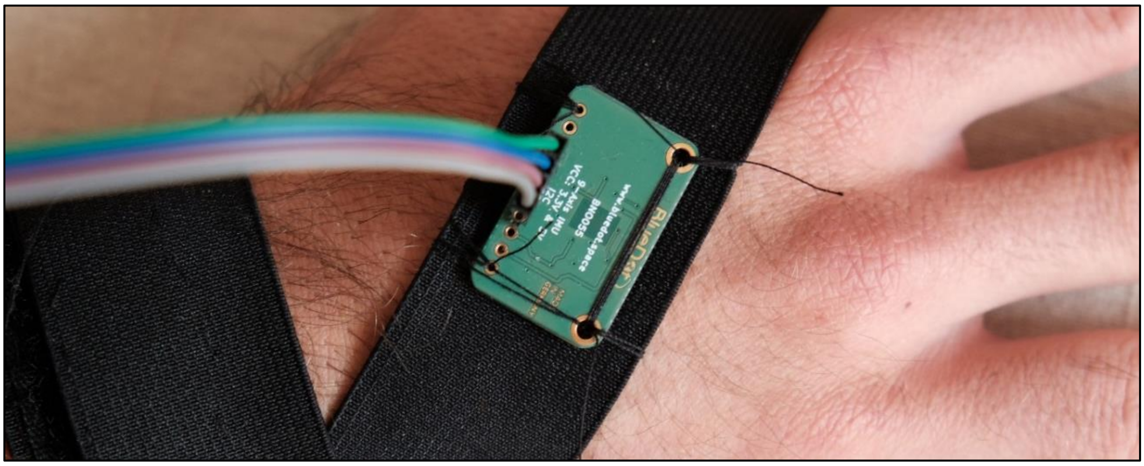

Figure 28 The Blue Dot BNO055 sensor used on the Expressor (Photo by author).

For the project's applications, the IMU sensor outputs the linear accelerometer data as well as the orientation data of the guitarist's hand. The sensor's data and its use are discussed in further detail in Ch. 7.6.

7.5.1.2. The Expressor: attachment straps

As already outlined, the idea of the right-hand setup is to capture the movements of the strumming hand. To this end, the IMU sensor must naturally be placed as closely to the hand as possible. After trying out several positions, the back of the hand proved to be the best place to position the IMU sensor for it to be able to track hand movements. Additionally, the ESP32 needs to be placed in proximity to the IMU sensor because the cables connecting the two are quite short. Apart from these two parts, a power supply in the form of a battery pack must also be worn to power the ESP32 and, in turn, the sensor. Consequently, a solution for attaching the three components to the guitarist had to be found that 1) allows the components to operate as intended and 2) does not interfere (too much) with guitarists' ability to play. To this end, it was decided to use custom-made textile straps that can be worn by guitarists upon which the hardware components are sewn. Several versions and ameliorations had to be made before the solution currently in use was developed.

The current solution consists of three wearable pieces and is shown in Fig. 29.

A rubber band that can be worn around the hand and wrist places the IMU sensor on the back of the hand. The rubber fabric allows for some flexibility, increasing the chances of it fitting different hand/wrist sizes and it comes with a sewn-on hook-and-loop fastener to fasten it according to one's needs.

The ESP32 is sewn onto a strip of denim with attached hook-and-loop fastener straps. The device is worn around the forearm and its tightness can again be individually adjusted.

The battery pack is intended to be worn around the upper arm to minimize noise interference stemming from the electrical current getting picked up by a guitar's pick-ups. It consists of a broad rubber band with hook-and-loop fastener straps similar to the ESP32's device. The battery pack can easily be attached and detached using, again, hook-and-loop fasteners.

All attachment devices are made from black or denim fabric to be as neutral and appealing as possible to users.

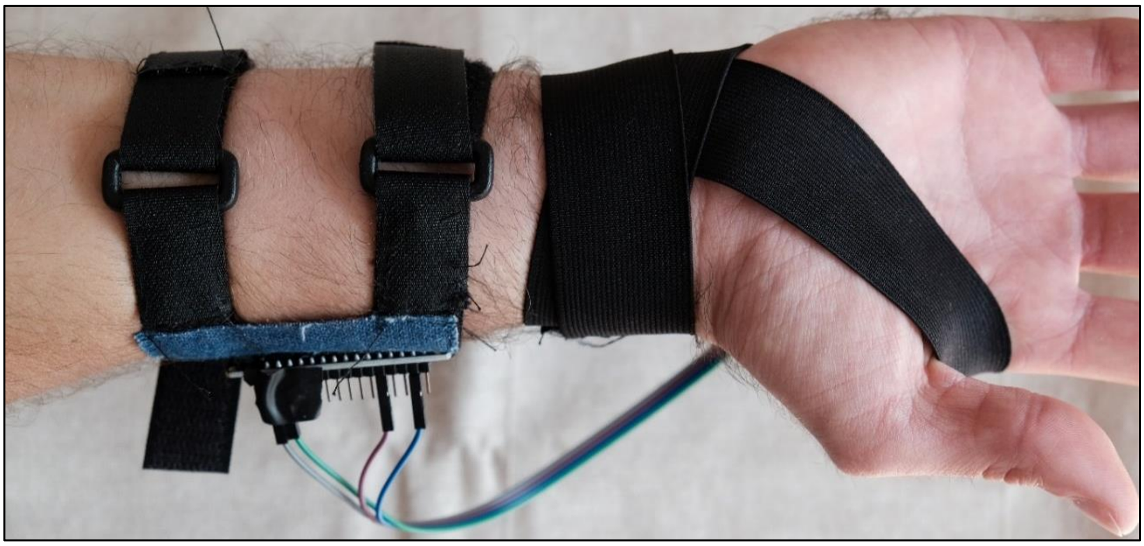

Figure 29 Photo of the attachment device of the Expressor (Photo by author).

7.5.1.3. The Expressor: power supply

As already touched upon above, noise introduced to the guitar's audio signal by electrical current via the guitar's pick-ups was an issue in finding the proper power supply for the Expressor. Initially, a small power bank was intended for the job, however, the power bank itself as well as the ESP32 when powered by the bank via the micro-USB input introduced a lot of noise to the audio signal. Noise introduction could be significantly reduced by powering the ESP32 via the VIN and ground power pins using a battery pack that is itself placed farther away from the guitar's pick-ups. Accordingly, a battery pack consisting of three AA 1.5 V alkaline batteries providing a total of 4.5 V. is used to power the Expressor.

7.5.2. The Expressionist: hardware

The Expressionist is the main hardware unit of the right-hand setup. It receives and processes the data sent by the Expressor and uses it to control guitar effects pedals via their expression pedal input. It is comprised of another ESP32, a digital potentiometer and its circuit, an indicator LED and an expression pedal output and cable. These components are housed in an effect-pedal shaped and sized box.

7.5.2.1. The Expressionist: working principle

The Expressionist is intended to work like a common expression pedal with the difference that instead of being controlled via foot, it can be set via the motion data of the strumming hand. In order to develop said mechanism, it was important to understand how conventional expression pedals work. The actual pedal of the expression pedal is connected to a potentiometer moving according to the pedal settings. This potentiometer is connected to an output jack and cable that is, in turn, connected to a guitar effect pedal's expression pedal input. The guitar effect pedal sends out a control voltage across the cable that goes through the expression pedal's potentiometer and back to the guitar effect pedal. By adjusting the pedal, the resistance of the potentiometer changes which alters the amount of control voltage being returned to the guitar effect pedal. The effect pedal then varies the effect parameter it controls accordingly. In the case of expression pedals TRS jacks consisting of ring, tip and sleeve and a TRS cable must be used to carry the signal (Mission Engineering Inc., n.d.).

The Expressionist basically follows this working principle but replaces the mechanical potentiometer controlled by the foot pedal with a digital potentiometer that can be digitally controlled via the ESP32.

Regarding the digital potentiometer, another MCP4251 is utilized – the same make of the one used in the Mothership. It offers an 8-bit resistor network resolution, resulting in 257 (0-256) steps and includes two separately controlled potentiometers. It features an operating voltage range from 2.7 V to 5.5 V making it possible to power it via the ESP32's 3.3 V supply and is controlled via the Serial Peripheral Interface (SPI) interface (Microchip Technology Inc. 2008, p. 1).

Based on the blog by Matthew McMillan (2014), it is connected to the ESP32 as follows:

- MOSI/SDI – GPIO 23
- MISO/SDO – GPIO 19
- SCK – GPIO 18
- CS – GPIO 5
- Shutdown pin – GPIO 4 (digital) and a 4.7k Ohm pull down resistor to ground
- V_{ss} – 3.3 V
- V_{dd} – Ground
- WP – 3.3 V
- P0B – Ground
- P0A – 3.3 V
- P0W – LED with 220 Ohm resistor to ground
- P1B – sleeve of output jack
- P1A – ring of output jack
- P1W – tip of output jack

Fig. 30 below shows the connections of the MCP4251 as shown in its datasheet.

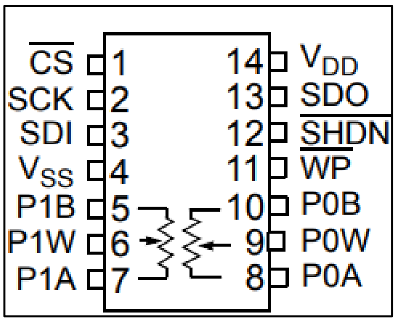

Figure 30 MCP4251 connections II (Screenshot by Author).

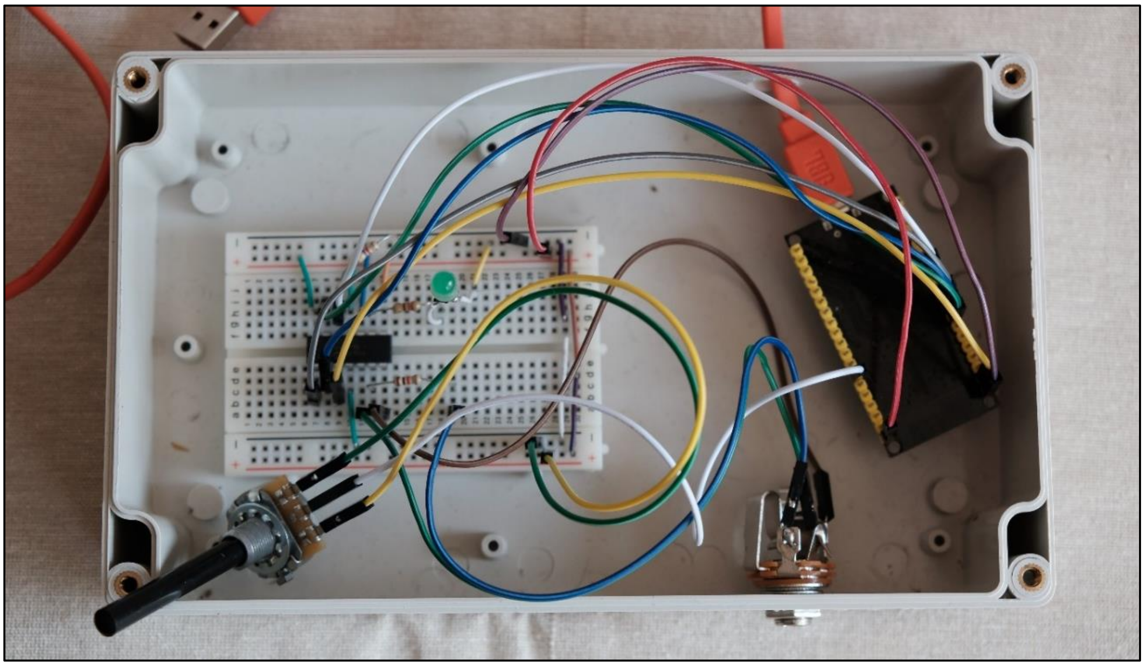

Figure 31 Photo of the circuit of the Expressionist (Photo by author).

With it being the only circuit in the Expressionist's box and thus no space issues had to be considered, it was decided to leave it on the breadboard since soldering it onto a stripboard would have posed an unnecessary risk to the electrical components involved (compare Fig. 31).

As depicted in Fig. 31, the circuit also features a LED whose brightness mirrors the expression pedal settings. In addition to the digital potentiometer, the Expressionist also has a mechanical potentiometer that is used to switch between linear accelerometer data or orientation data coming from the Expressor to control the digital potentiometer. This is explained in further detail in Ch. 7.6. This potentiometer is connected to the 3.3 V and ground rails of the breadboard and to GPIO 32 of the ESP32.

7.5.2.2. The Expressionist: power supply

While conventional expression pedals are passive and need no power supply (Mission Engineering Inc. n.d.), the Expressionist's ESP32 as well as digital potentiometer need 3.3 V to function. As no audio signals are processed in the Expressionist, it is safe to use a power bank without risking noise introduction. Apart from the power bank, the Expressionist could also be supplied by a power socket when using a 5 V adapter.

7.5.2.3. The Expressionist: housing

Like the Mothership, the components of the Expressionist are housed in a box made from ABS plastic. The Expressionist's box is slightly smaller, measuring 20 x 12 x 6 cm. A few adjustments had to be made including two 10-cm holes drilled into the sides to fit the stereo jack and the power supply. Furthermore, one 10-cm hole was drilled into the lid for the mechanical potentiometer setting the kind of IMU data used. Additionally, a smaller hole was drilled to accommodate the indicator LED.

7.6. Right-hand setup: software

This chapter is dedicated to the development of the software for the right-hand setup. As it was done for the hardware description, this section will be divided into the codes done for the Expressor and for the Expressionist. Like all codes for this project, the codes for these two devices were written using the Arduino Integrated Development Environment (IDE).

7.6.1. The Expressor: code

The code written for the Expressor handles the following tasks:

1. Interface with the BNO055 IMU sensor and gather data
2. Process the data (rolling average)
3. Send the data to the Expressionist

The flowchart in Fig. 32 depicts the workings of the code.

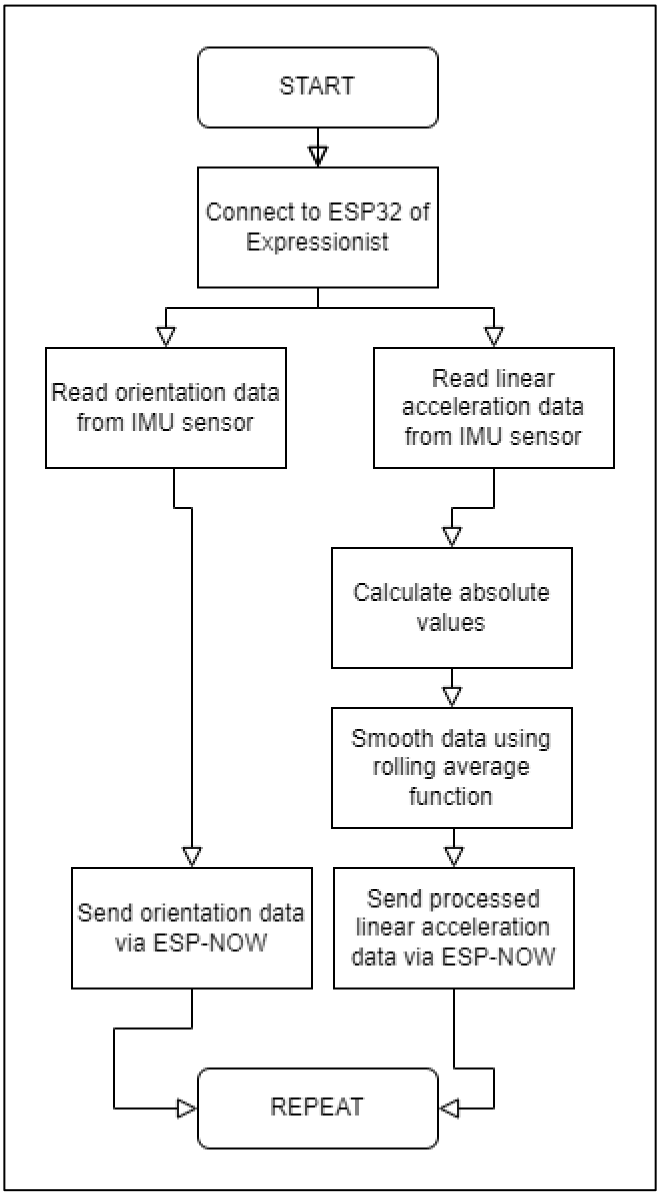

Figure 32 Flowchart depicting the code logic of the Expressor (Image by author).

As already touched upon, the BNO055 works via 3.3 V and I^2C, and connections with the ESP32 were made accordingly. To interface with the sensor, the Adafruit Unified BNO055 Driver library and the Adafruit Unified Sensor Library were used (Adafruit Industries n.d.).

In principle, the BNO055 sensor can take different measurements concerning an object's movement and positional data. Consequently, the first step was to determine what kind of data is suited best for tracking the strumming/picking movements of the hand and, subsequently, for controlling effects. To this end, several tests were conducted that consisted of playing guitar with the sensor worn on the back of the hand and the incoming sensor data being analyzed. During the tests, two kinds of sensor data exhibited the most potential:

1. Orientation data and in particular the hand's movement along the sensor's y-axis
2. Linear acceleration data and in particular the hand's acceleration along the sensor's x-axis

To better understand the data and evaluate the best way to process them for effects controlling, data sets of these two kinds were recorded and plotted over time. For this, the Microsoft Excel add-on "Excel Streamer" was used that allows to stream and record sensor data coming in over the serial bus directly into Excel. For each data set, the same strumming pattern was played for two bars at a tempo of 120 bpm using a metronome to ensure comparability. Furthermore, experiments included using different window sizes of a rolling average function implemented in the code, resulting in different degrees of data smoothing.

Fig. 33 depicts the changes of the orientation data along the y-axis with no averaging function implemented. The values range from -65 to -22 degrees and the ups and downs of the strumming pattern can be seen clearly. In Fig. 34 and Fig. 35, the window size of the rolling average function has been increased to 10 and 100 samples respectively. Here, it is evident that the bigger the window size, the smoother the data with values starting to converge to a single value around -45 degrees. This corresponds to the expectations prior to the tests.

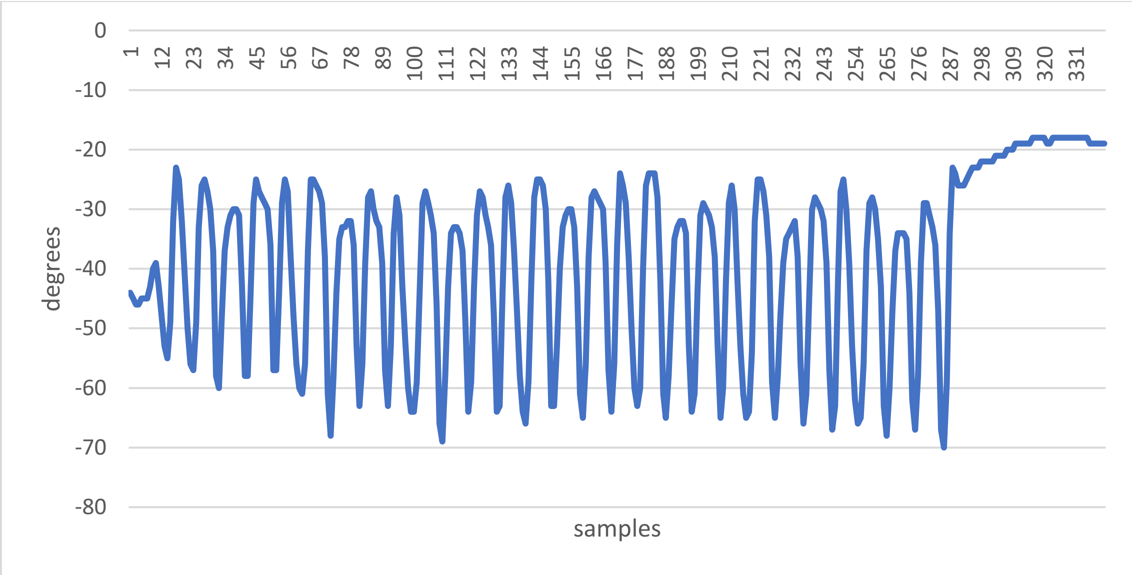

Figure 33 Orientation y-values while strumming 2 bars at 120 bpm (Graph by author).

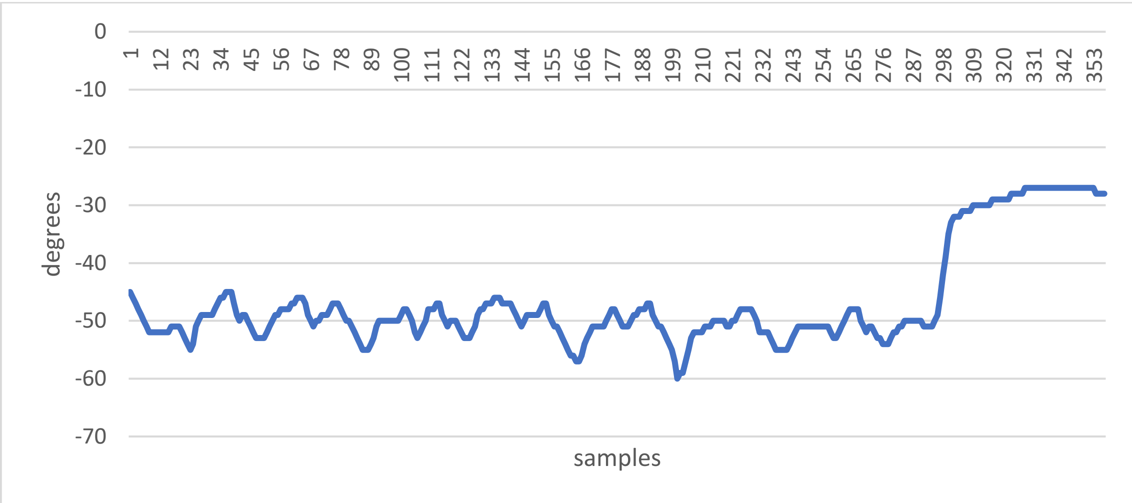

Figure 34 Orientation y-values while strumming 2 bars at 120 bpm with window size = 10 (Graph by author).

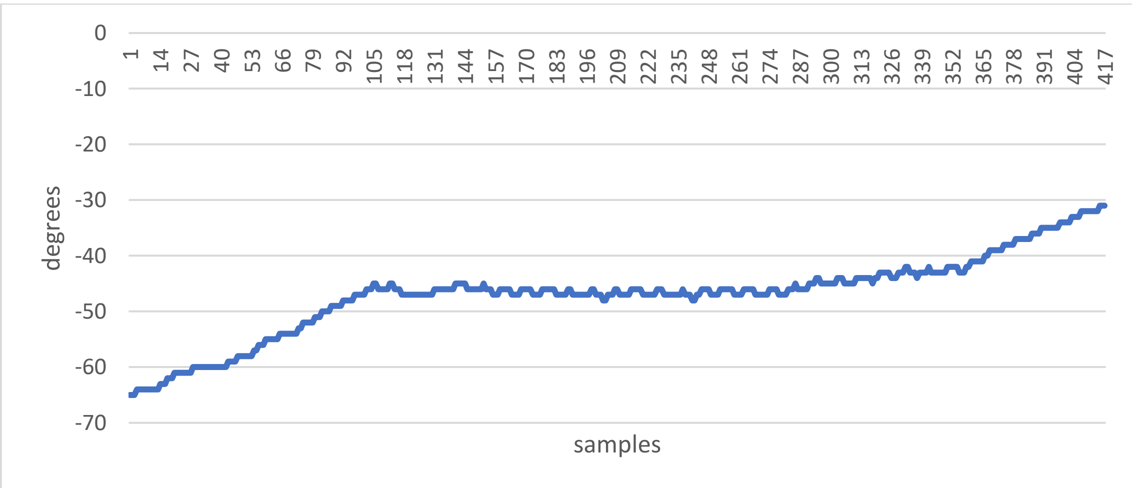

Figure 35 Orientation y-values while strumming 2 bars at 120 bpm with window size = 100 (Graph by author).

A similar relationship can be observed when looking at the linear acceleration data. Fig. 36 shows the course of the linear acceleration values along the x-axis with no averaging. The strumming pattern can be easily discerned and reflects the data even more directly than the orientation data. The values range from -10 to 10 m/s^2 on average. As it was done with the orientation data, a rolling average with increasing window size was implemented. Here, the smoothing of values can be achieved with a much smaller window size compared to the orientation data: while a window size of 5 samples leads to smoother curves and a reduced range of -2 to 4 m/s^2, window size 20 already results in values ranging only from 0 to 1 m/s^2.

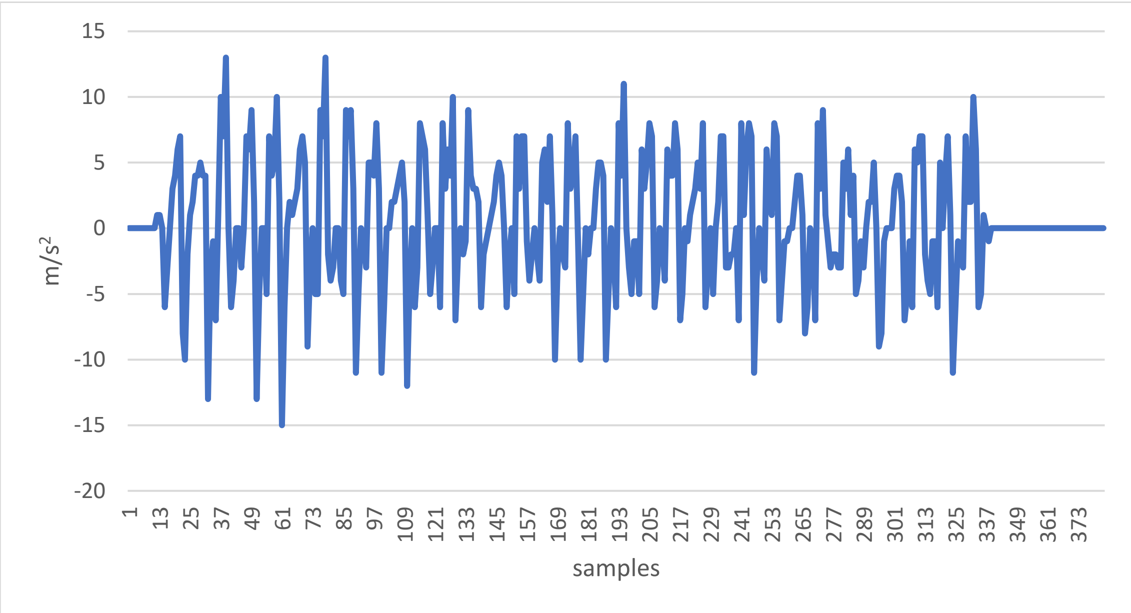

Figure 36 Linear acceleration x-values while strumming 2 bars at 120 bpm (graph by author).

As no effect can be reasonably controlled with the average acceleration being 0, it was decided to calculate the absolute values from the measurements first before calculating the rolling average. Following this procedure, six different data sets were recorded and plotted with window sizes of the rolling average function being 10, 20, 30, 50, 70 and 100 samples, respectively. By calculating the absolute values first, a positive average acceleration of the strumming hand can be measured (and used to control effects). With increasing window size, the values converged to the average of 3 m/s^2. Tests in conjuncture with effects pedals revealed that a window size of 30 results in sufficiently stable values while reacting fast enough to changes in strumming intensity. With the IMU sensor operating with a delay of 50 milliseconds between each sample, the window size of 30 samples corresponds to 1.5 seconds. The graphs below show the absolute values of linear acceleration with window size 30 (Fig. 37) and window size 100 (Fig. 38).

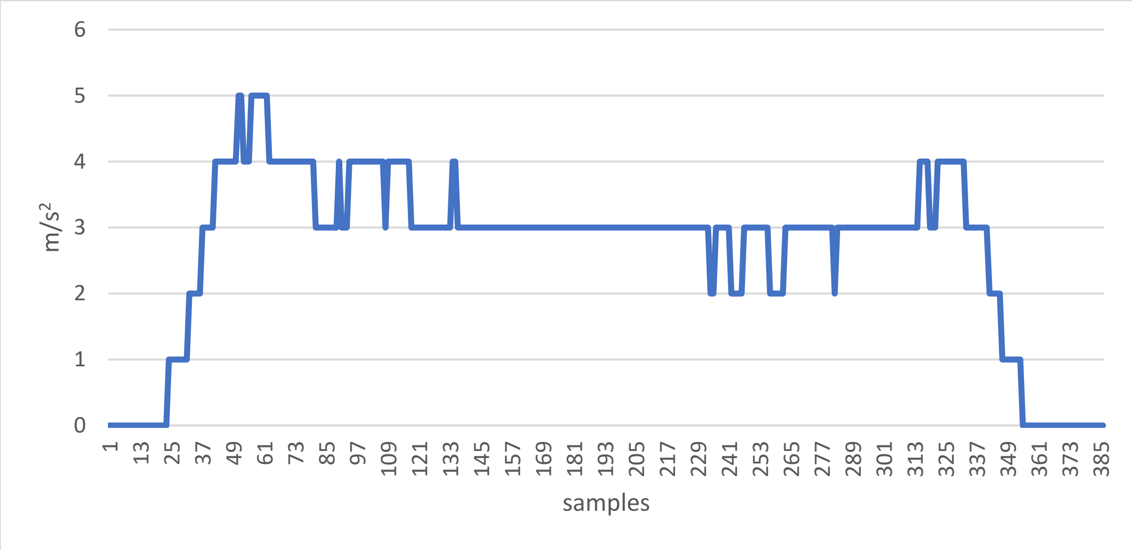

Figure 37 Absolute linear acceleration x-values while strumming 2 bars at 120 bpm with window size = 30 (Graph by author).

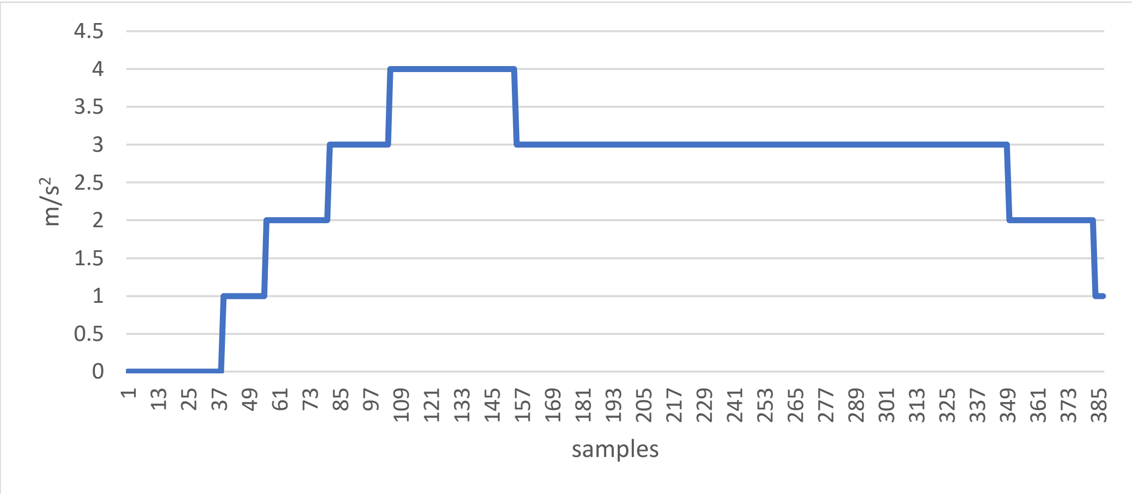

Figure 38 Absolute linear acceleration x-values while strumming 2 bars at 120 bpm with window size = 100 (Graph by author).

In the course of the project the features of the Expressor were augmented: at first, the Expressor measured only the “raw” orientation data along the y-axis and the “raw” linear acceleration data along the x-axis with no averaging done at all. However, as these two served a very similar purpose in controlling effects, it was decided to switch from the “raw” linear acceleration data to the processed alternative with absolute values and rolling average calculations. The system now allows to choose between “raw” orientation data and processed linear acceleration data to control effects pedals.

The Expressor always sends its data via ESP-NOW to the Expressionist.

7.6.2. The Expressionist: Code

The code written for the Expressor handles the following tasks:

1. Receive data from the Expressor
2. Process the data (constrain and map)
3. Decide if orientation data or linear acceleration data is used for effects control
4. Alter wiper position of digital potentiometer according to data (and thus control the effect pedal via the expression pedal input)

The flowchart Fig. 39 depicts the workings of the code. Below, the steps are outlined in more detail.

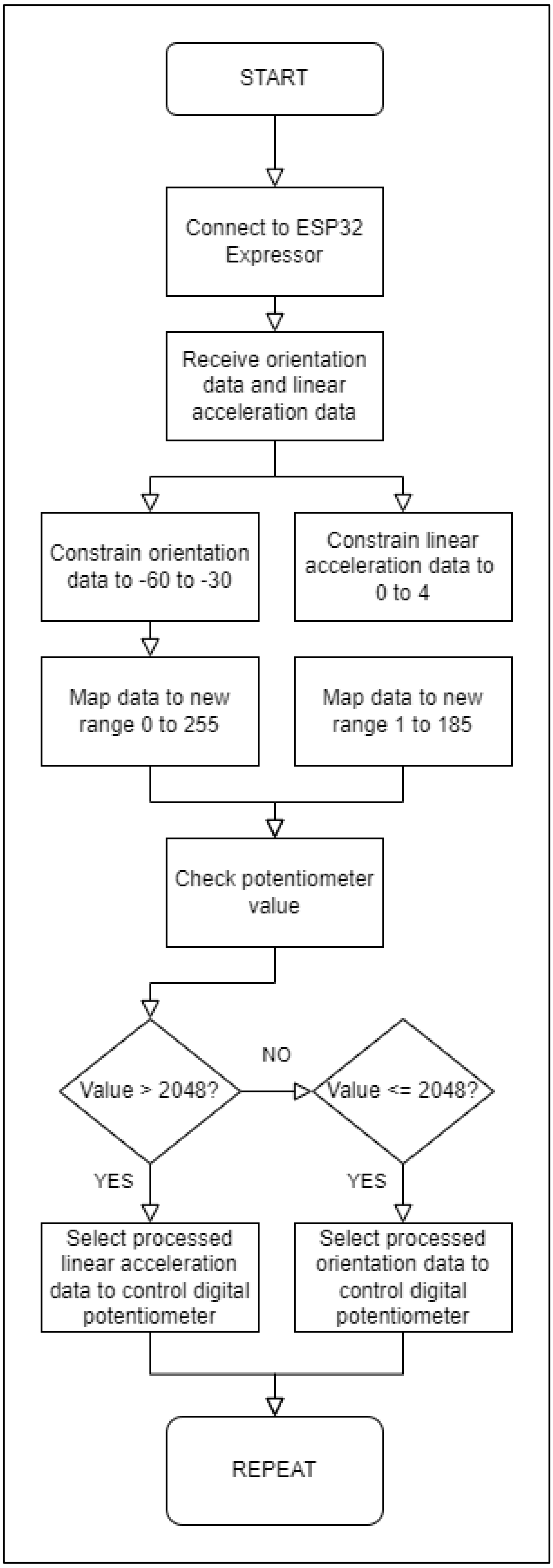

Figure 39 Flowchart depicting the code logic of the Expressionist (Image by author).

As depicted above, the Expressionist first receives the data sent by the Expressor via ESP-NOW. Then it proceeds to process the data for its use of controlling effects pedals.

With the data of the BNO055 IMU sensor captured and plotted, the next step was to determine how this data should be mapped in order to make it possible to control guitar effects pedals in a reasonable and useful way. The mapping of the data is done by the ESP32 contained in the Expressionist with the Expressor just being responsible for measuring and averaging. In order to establish suitable mappings, the Expressor/Expressionist combination was tested in conjuncture with actual guitar effects pedals.

Initially, the orientation data and linear acceleration data were used without any smoothing done. In that way, these two kinds of data appear to provide a high degree of real-time control over effects.

By using the orientation data, the strumming movements of the hand can be detected quite accurately, and guitar players are able to sweep through the effect parameter's range from low to high and back. This function appears to work very well with Wah-Wah pedals that can be controlled via an expression pedal input. For the tests, "The Worm" by Electro Harmonix was used. In working with this pedal, the initial range of motion along the y-axis was constrained from -65 to -22 degrees to -60 to -30 degrees. This ensures that the highest and lowest settings of the pedal are hit more frequently. The range from -60 to -30 degrees was then mapped to the range 0-255 to control the digital potentiometer which, in turn, controls the effect pedal. These settings work well in conjuncture with the Wah-Wah effect and the playing style typically associated with it. Other effects, however, do not seem to be suited for this data and mapping because constant sweeping through the whole range of the controlled effect parameter is not always desirable and results in a wonky and uneven sound. For instance, the mapping was also tested with a Boss PS6 – Harmonist pitch shifter. By sweeping the hand down while strumming a chord, harmonies can be added to the original sound of the guitar with the rise and fall time of the harmonies controlled by the velocity of the hand motion. While this may be applicable for some songs, guitarists are restricted to moving the hand very specifically and conventional strumming is not possible since then, the harmonies added are mostly out of tune.

The linear acceleration data also works to detect the movements of the right hand. While players cannot sweep through settings like it can be done using orientation data, they can control the amount of effect added by altering the intensity of their strumming. The range of values was also slightly constrained from -10 to 10 m/s^2 to -7 to 7 m/s^2 and mapped to 0-255 steps. That way, it also works well in conjuncture with a Wah-Wah effect.

Nevertheless, the Wah-Wah effect appears to be the only effect that can be reasonably controlled with “raw” orientation and linear acceleration data. Other effects like reverb or delay require more stable values and no constant sweeping through an effect parameter.

Consequently, the averaged orientation and linear acceleration data were also tested in conjuncture with guitar effects pedals. In the case of the orientation data, a window size of 20 results in values ranging between -50 and -40 degrees, with values almost converging to a single value. This makes it applicable to control effects in a more constant way instead of erratic changing of effect parameters. Using a guitar effect pedal as reference, the orientation data’s y-value was first constrained to a range of -42 to -30 degrees and then mapped to 255-0. Thus, the effect is at or around its highest setting as long as guitar players strum in a consistent way and the effect falls to its lowest level if players stop strumming and let their hand sink down.

Even more promising was the averaged linear acceleration data. The processed data was constrained to be between 0-4 m/s^2 and mapped to a range of 1-185. That way, an effect is less pronounced when players strum lightly or (finger-)pick, and an effect is more pronounced when players strum harder and more intensively. This works particularly well with the delay effect.

In the end, the “raw” orientation data and the processed linear acceleration data using a window size of 30 were used during the interviews, with the first being primarily used for the Wah-Wah effect and the latter for a delay effect.

The types of data, their processing and their mappings, interview usage and exemplary effects are summarized in Tab. 5 below:

Type of data	Processing	Range used	Mapping	Interview usage	Exemplary effects
“Raw” linear acceleration data	No processing	Constrained to -7 to 7 m/s^2	0 to 255	Used in interviews 1-5	Wah-Wah
“Raw” orientation data	No processing	Constrained to -60 to -30 degrees	0 to 255	Used in interviews 1-9	Wah-Wah/Pitch shifter
Averaged linear acceleration data	Absolute values + rolling average with window size 30	Constrained to 0 to 4 m/s^2	1 to 185	Used in interviews 6-9	Delay

Table 5 Summary of data usage of the right-hand setup (Table by author).

8. Empirical study

This chapter describes the research design and objectives of the empirical study based on interviews and usability tests with nine guitarists.

8.1. Research design and objectives

The aim of the study is two-fold. On one hand, the study sets out to further contribute to the exploration of the qualities, characteristics, and challenges of the ecology of electric guitar players. It aims to deepen the findings made above and, moreover, to provide additional, practical insights into the environment of guitarists. The real-life ecology of guitarists is examined and the practical prerequisites for the Dextoria system are identified and can subsequently be evaluated. On the other hand, usability tests are conducted to evaluate the Dextoria system in a practical setting by nine electric guitar players. Thus, the study represents the ultimate test for the developed system and will scrutinize its capabilities as well as reveal its design shortcomings.

For the interviews, the qualitative research method has been selected. Qualitative research can be defined as “an unstructured, exploratory research methodology based on small samples that provides insights and understanding of the problem setting” (Malhotra 2020, p. 153).

Depth interviews (expert interviews) were selected as the appropriate means to gather data. Depth interviews are unstructured, direct interviews held on a one-on-one basis. Although the interview follows a certain guideline, many details such as wording and order of questions may be altered by the interviewer, depending on the interviewee's answers (Malhotra 2020, p. 166). According to Malhotra (2020, p. 169), depth interviews are an effective method if detailed probing of the respondent and detailed understanding of complicated behavior is required. Furthermore, depth interviews are recommended if the interviewees are professionals of some sort and/or in situations where the product consumption experience is of a sensory and emotional nature.

Considering these application suggestions, depth interviews were deemed an appropriate method as (1) the interviewees are professionals, (2) the topic of interest is of a sensory nature and is rather complex.

Apart from the responses of the interviewees, observations made by the author during the interviews, especially during the usability tests, are also considered and will be listed in Ch. 9. The observations include the participants' reactions while testing Dextoria as seen by the author as well as more general issues such as reliability of the left-, and right-hand setups or their battery life.

8.2. Selection of interviewees

For this study, a total of nine guitarists were involved. The experts were chosen in accordance with the potential "target market" of the Dextoria system: electric guitarists with substantial experience in performing live and in using guitar effects pedals on stage. Additionally, it was tried to interview guitarists from different musical backgrounds to get a more holistic view on the application potential of Dextoria across musical genres. As far as musical genres are concerned, the majority of guitarists come from a rock-oriented background with several different sub-genres of rock music being represented. Nevertheless, two guitarists come from a non-rock music background. The guitarists were found in different ways. Only three guitarists were known personally to the author prior to the interviews – two being guitar players in bands known to the author and one being a university teacher. Four were found by searching or asking for guitarists playing in bands in and around Graz and at the "Jazz Institut" of the Kunstuniversität Graz (KUG). The remaining two were conveyed to the author by two of the guitarists already interviewed.

All nine guitarists participated voluntarily and did not receive any kind of compensation. Anonymity was guaranteed to all interviewees; hence they will be referred to as “participant” or “P”, followed by a randomly assigned number. More details regarding the participants are listed in Ch. 9.

8.3. Execution of interviews/usability tests

The interviews and usability tests were all conducted in person at a place specified by the respective interviewee. As one of the study’s objectives was to investigate the degree of integration of Dextoria into different guitar setups, the participants were encouraged to select the place where they usually play guitar and have their guitar rig set up. Thus, five interviews/tests were held at the participants’ homes, three were held at the participants’ studio or rehearsal rooms and one was held at the audio studio of FH JOANNEUM Graz. The majority of interviews/tests were held on a one-on-one basis; only one was conducted with two guitarists simultaneously due to time/place constraints of one participant.

The sessions were split into three parts: firstly, participants were asked general questions regarding the ecology of guitarists and the handling of effects. Subsequently, the Dextoria system was set up and the participants tested the system for as long as they deemed necessary, usually 15 to 25 minutes. After the test session, the participants were interviewed again regarding their experiences and thoughts concerning Dextoria.

The interviews/tests were all held during the month of April 2023 and lasted approximately one hour to one and a half hours. An interview guideline was used to guide the conversation. Since all participants live in Austria, the interviews were held in German. The interviews and the test sessions were recorded using a Zoom H4n handheld recorder. The recordings were subsequently transcribed for further analysis. All interviewees were apprised of the recordings and expressed their consent.

8.4. Interview guideline

For the interviews and usability tests, a guideline was developed based on the thesis’ research hypothesis. The guideline is divided into two parts with the first half asking for general information about the ecology of guitarists while the second half focuses on the playing experience and thoughts about the Dextoria system. There is a total of 27 questions – 12 questions in the first part and 15 questions in the second part of the guideline. All questions were formulated and asked in an open, non-suggestive format. In accordance with the interviews being held in German, the guideline is written in German as well. The interview guideline, translated into English, can be found in the appendix.

8.5. Qualitative content analysis

This Master's thesis applies the qualitative content analysis by Phillip Mayring to analyze the information gathered during the interviews and usability tests. Mayring discerns three basic types of interpretation of (verbal) material: summary, explication, and structuring. This thesis applies the summary technique which aims to reduce the material through abstraction to a compressed amount of information while ensuring that the essential and fundamental elements of the material are retained (Mayring 2015, p. 67). For the summary technique, the following procedure is recommended:

- Step 1: paraphrasing
- Step 2: generalization
- Step 3: 1st reduction
- Step 4: 2nd reduction

In the first step, interview passages unrelated to the content are eliminated while relevant phrases are paraphrased and summarized into short statements of identical stylistic level. In the second step, the abstraction level is defined and all phrases lying below this level are generalized. Subsequently, phrases that are now synonymous can be filtered out while phrases that are still relevant to the content are retained. In the fourth and final step, phrases that are content-related are summarized into common statements (Mayring 2015, pp. 70-72).

The procedure described above was carried out for each interview. For the analysis a category system was developed using an inductive approach with the individual categories being derived from the material at hand rather than using pre-defined theoretical concepts as basis (Mayring 2015, p. 85). A condensed version of the spreadsheets which were used to conduct the analysis can be found in the appendix.

9. Empirical Findings

This chapter presents the empirical findings obtained from the interviews and usability tests of Dextoria, using the qualitative content analysis of Mayring. The findings are summarized using the following content categories (see Tab. 6).

Category
C1: Personal background
C2: Musical genres
C3: Ecology of guitarists/performance setup
C4: Ecology of guitarists/controlling effects
C5: Technical integration left-hand setup
C6: Musical integration left-hand setup
C7: Potential improvement left-hand setup
C8: Technical integration right-hand setup
C9: Musical integration right-hand setup
C10: Potential improvement right-hand setup

Table 6 List of categories used for content analysis (Table by author).

Categories C1, C2, C3 and C4 summarize data gathered during the first part of the interviews regarding general features of the ecology of guitarists. Categories C5, C6, C7, C8, C9 and C10 highlight the results obtained from the interviews after the usability tests of Dextoria concerning the individual impressions of Dextoria's left- and right-hand setups.

9.1. C1: Personal Background / C2: Musical genres

First of all, the personal as well as the musical backgrounds of the participants were examined. On one hand, this served as a double-check to ensure that all participants fulfill the requirements to act as an expert in this study. Said requirements include being an advanced electric guitar player and having substantial experience in playing electric guitar in live performances. On the other hand, personal and musical backgrounds were recorded in order to find out how they might influence the perception and evaluation of the Dextoria system. Information about each participant is summarized below in Tabs.s. 7-9.

P#	Age	Gender	Guitar experience in years	Stage experience in years
P1	60	Male	45	45
P2	61	Male	50	46
P3	22	Female	10	8
P4	42	Male	25	20
P5	67	Male	53	50
P6	39	Male	27	26
P7	39	Male	30	24
P8	34	Male	20	18
P9	67	Male	55	54

Table 7 Information about participants I (Table by author).

	Age	Guitar experience in years	Stage experience in years
Mean value	47.89	35	32.33
Standard deviation	16.22	16.16	16.54

Table 8 Information about participants II (Table by author).

P#	Number of annual gigs	Performance locations	Area played	Genres played live
P1	20-30 times	Large festivals (Harley-Treffen) and smaller clubs	International	Rock, blues, funk, singer-songwriter
P2	Past: 40-50 times Now: 25 times	Concert halls, cultural events, company celebrations	International	Rock, blues, jazz, pop-rock
P3	12 times	Concert halls, jazz clubs	National	Jazz (modern + traditional)
P4	Now: 4-5 times	Medium festivals (Augartenfest, Rostfest), smaller clubs (Explosiv, Music House)	International	Punk rock, black metal
P5	20 times	Smaller clubs, large concert halls (Stefaniensaal, Helmut List Halle)	International	Experimental, electronic, improvised music
P6	Past: 100 times Now: 10-15 times	Large festivals (Nova Rock, Donauinselfest), concert locations	International	Rock, rock’n’roll, 60s, alternative rock
P7	Past: 40 times	Concert locations, smaller clubs	National	Indie rock
P8	Past: 30 times Now: 20 times	Concert locations, events	National	Rock
P9	Past: a lot; up to 62 times in summer alone Now: 10 times	Concert locations (Wörthersee), smaller stages	International	Rock, pop (commercial), funk

Table 9 Information about participants III (Table by author).

As can be seen in Tab.s. 7, 8 and 9, the requirements of being an advanced electric guitar player and having substantial experience in playing electric guitar in live performances appear to be well fulfilled. It proved to be a challenge to find female electric guitar players with even inquiries at universities or (cultural) organizations yielding no results. However, it was considered very important to include at least one female guitarist in the study and thus, the smaller guitar and stage experience of P3 was accepted.

9.2. C3: Ecology of guitarists/performance setup

The performance setup of the participants was examined in order to determine its characteristics and demands which in turn can be used to evaluate how well the Dextoria system can be integrated into such environments.

P1, P3, P6 and P7 state that the live guitar setup should not be complex but rather configured in a straightforward and easy way. Correspondingly, all participants but P5 use the basic signal chain: electric guitar – effects pedals – guitar amplifier. In fact, P9 even uses just one modeling amplifier (Kemper) that simultaneously serves as guitar amp and effects processor.

Nevertheless, P9 also states that he has experimented a lot with his setup, trying out various effects and combinations. Furthermore, P5 has a very elaborate setup and even uses two different signal chains simultaneously.

P4 and P5 alter their live setup depending on the musical genres played.

The analysis shows that despite the wish for a simple setup, a lot of different effects are used by the interviewed guitarists. Tab. 10 shows frequently mentioned effects:

Effect type	Description	Used by participant #	Total
Overdrive	Overdrive pedals clip the guitar signal resulting in a distorted and compressed sound (Bader n.d.).	P1, P3, P4, P5, P6, P7, P8, P9	8
Delay	A delay repeats the incoming guitar signal (Bader n.d.).	P1, P3, P4, P5, P6, P7, P8	7
Booster	A boost pedal adds extra gain and volume to the sound (Bader n.d.).	P1, P3, P4, P7, P8	5
Tuner	Allows for tuning the guitar (Bader n.d.).	P1, P4, P6, P7, P8	5
Reverb	Reverb adds depth to the guitar sound, making it sound as if it would have been recorded in a tunnel, a church, a hall, etc (Bader n.d.).	P1, P3, P4, P5, P6	5
Wah-Wah	Wah pedals work using a peak resonance filter boosting a certain	P1, P4, P5, P8	4

	range of frequencies. Said range is moved according to the foot movements creating a spectral glide (JustinBeckner 2019).		
Modulation effects (e.g., phaser, flanger) *	Flanger pedals work similar to chorus pedals and modulate the delay time with an LFO, generating frequency cancellations. Phasers also generate frequency cancellations, but they use an all-pass filter to change the phase relationship of copied and original signals (Kody 2021).	P1, P6, P8	3

Table 10 Frequently mentioned effects (Table by author).

*P1 uses modulation effects in general without specifying the exact kind of modulation effects. P6 uses a Phaser while P8 uses a flanger.

Tab. 11 summarizes less frequently mentioned effects:

Effect type	Description	Used by participant #	Total
Fuzz	Fuzz creates an “over the top” distortion sound using a square wave to achieve its characteristic spikey sound (Brill 2015; Robertson 2022).	P1, P6	2
Distortion	Distortion is very similar to overdrive but typically applies heavier clipping and is more saturated with more gain (Bader n.d.; Robertson 2022).	P5, P9	2
Equalizer	Using an equalizer pedal allows for attenuating or boosting certain frequencies of the guitar signal (Bader n.d.).	P4, P7	2
Tremolo	Tremolo pedals modulate the amplitude of the guitar’s signal (Bader n.d.).	P5, P6	2
Compressor	A compressor reduces the dynamic range of the guitar signal (Bader n.d.).	P4, P5	2
Multi-effects pedal	As the name suggests, multi-effects pedals can produce several different effect types (Robertson 2022).	P2, P5	2
Noise Gate	This pedal closes the signal line if volume levels drop below a set threshold eliminating hum and noise (Robertson 2022).	P4	1
Feedback Generator	This pedal generates natural feedback at any volume (DigiTech n.d.).	P4	1
Pitch Shifter	A pitch shifter pitches the guitar signal up or down based on set intervals (Seidler 2020).	P5	1
Filter	A filter pedal enhances the guitar signal by adding and removing certain frequencies. They are capable of more	P5	1

	drastic sound alterations than a conventional EQ pedal (Stent n.d.).		
Ring Modulator	A ring modulator is basically an audio mixer which combines two signals and outputs their sum and difference while subtracting the original frequencies (Jenkins 2022).	P5	1
Granular Synthesizer	Granular synthesis uses granulation where audio samples are broken down into tiny segments of audio which can then be processed (Brown 2019).	P5	1
Bitcrusher	A bitcrusher reduces the resolution of an audio signal, thereby producing distortion (Wikipedia contributors n.d.a).	P5	1
Organ emulator	This pedal opens the possibility to transform the guitar tone into organ tones (Electro-Harmonix n.d.).	P8	1
Talk box-style effect	Using a talk box, guitarists can shape the frequency content of their guitar signal using mouth movements and speech (Wikipedia contributors n.d.b).	P9	1

Table 11 Less frequently mentioned effects (Table by author).

Sometimes, different effect pedal models/brands are used for the same type of effect; for example, P6 uses one analog delay and one digital delay while P7 uses 2 different overdrives.

Two participants (P2 and P5) also use digital multi-effects pedals. P2 uses a multi-effects pedal in combination with (analog) single effects units that were, unfortunately, not named specifically and hence P2 is not represented in the lists above apart from the multi-effects pedal.

All participants use guitar amplifiers as their last element of the signal chain with only P5 stating that he would go directly into a PA if using an amplifier was not an option.

Of all nine participants, only P5 frequently uses an audio interface and laptop as part of his live performance setup. He is also the only one to use digital effects running on a computer when performing live.

9.3. C4: Ecology of guitarists/controlling effects

The way guitarists control their effects while performing was examined in order to determine the current standard procedures of controlling effects on stage and to highlight possible challenges or shortcomings of the current methods that may be mitigated by the Dextoria system. This category covers general aspects of effects control (part 1) as well as special aspects of effects control concerning the left-hand setup and right-hand setup respectively (parts 2 and 3). Finally, a brief summary of the results is given.

9.3.1. C4 part 1

The analysis shows that effects controlling while playing guitar during a live performance is perceived as a challenge by most participants (P1, P3, P4, P6, P7, P8 and P9) with several reasons being named. Only P2 explicitly states that controlling effects is no challenge (for him).

First of all, effects controlling while playing can be distracting according to P8, and P4 adds that it is difficult for guitar players as both their hands are involved in playing the guitar. Additionally, P4, P7 and P9 state that, as effects are usually on the ground in front of the player, they are physically difficult to access. Moreover, P4 mentions that players run the risk of activating or deactivating effects at the wrong time, for example not on the beat. Especially switching between rhythm and lead sound is cited as challenging by P8. It is stated by P1 and P3 that effects control is not trivial, instead it must be learnt, and one must get accustomed to controlling effects while playing. P1 adds that effects control must be mentally planned ahead of the song or at least well ahead of changing the sound.

Correspondingly, active effects controlling done by participants is usually limited to activating and disactivating effects during the song as needed. This is done by P1, P3, P4, P5, P6, P8 and P9. Nevertheless, P1 states that he sometimes performs up to eight switching acts in one song and P8 may need up to four switching acts to change from rhythm to lead sound. The effects in Tab. 12 are specifically mentioned when talking about activating and disactivating effects during the song:

Kind of (dis-)activated effect during song	Participant #
Overdrive	P1
Tremolo	P1
Reverb	P4
Delay	P4
Amplifier channel	P4
Preset change (for multi-effects-devices)	P9

Table 12 (Dis-)activated effects during songs (Table by author).

Apart from turning effects on and off, P2, P3, P4, P6, P7 and P8 state that they do not change individual effect parameters while playing. Instead, the effects settings are adjusted to taste prior to the performance e.g., during soundcheck. P3 states that some effects consistently remain turned on during the performance. P4 and P6 for example say that they tend to adjust individual effect parameters during performances only if readjustment or correction of settings are acutely necessary.

According to P4, whether active effects control while playing is actually desired or not depends on the individual attitude of the guitar player as well as on the musical genre played. He goes on to say that specifically in punk or black metal, active effects control is not really necessary.

Three participants state that they actively control individual effect parameters while playing. Tab. 13 summarizes examples in this context.

Kind of control for individual parameters	Participant #
Volume control via expression pedal	P2
Delay times via expression pedal	P9
Control of various effect parameters via expression pedal	P5
Control of various effect parameters via extra knob on electric guitar (custom construction)	P5
Control of various effect parameters via TouchOSC (tablet app)	P5

Table 13 Kind of control for individual parameters (Table by author).

9.3.2. C4 part 2

In the case of every participant, the rhythm guitar sound differs from the lead guitar sound. The extent of the differences depends on the musical genre commonly played.

For instance, according to P3, there is no substantial difference between rhythm and lead sound in jazz except the volume. Moreover, P4 states that solos tend to be short in punk and are even frowned upon resulting in less need for special effects for a solo.

P1, P3, P4, P6 and P7 are of the opinion that the lead guitar sound should be similar to the rhythm guitar sound, just louder.

To get the desired increase in volume, a booster or a compressor are applied. P3 uses the volume knob of the guitar to control the volume for lead/rhythm sounds.

For P2, P8 and P9, the rhythm sound tends to be clean to crunchy with the solo sound not only being louder but also more distorted. Furthermore, other effects may be applied to the solo sound (see Tab. 14).

Effects used for solos	Participant #
Delay	P2, P8, P9
Reverb	P2, P9
Chorus	P4 (used effect in the past)
Fuzz	P6

Table 14 Effects used for solos (Table by author).

In general, P3 and P8 state that they use the whole fretboard for their solos and P5 states that it cannot be precisely stated from which fret number on solos usually take place. P3 says that rhythm parts tend to be played in the lower parts of the fretboard while P4 states that he usually solos from the 12th fret on and never solos below the 7th or 9th fret.

Apart from different rhythm and lead sounds, P1, P3, P4, P7 and P8 say that there are other situations where guitar players may need two (or more) different sounds for one song. Only P2 states that he exclusively needs one sound. Different sounds are needed, for example, when cover songs are played (P3) or if individual parts of a song differ substantially from each other (P7) or if fills are frequently intermingled with rhythm guitar parts (P8).

9.3.3. C4 part 3

The participating guitarists hold different views on the importance of real-time control over effect parameters (while playing). P1, P5, P7 deem real-time control important or useful while P2, P3 and P9 explicitly state that for them, real-time control is not relevant. P1 and P4 deem real-time control a great challenge with P4 stating that for him playing guitar and controlling effects are perceived as separate tasks.

Tab. 15 summarizes the following effects and parameters that are controlled in real-time:

Effect/parameter controlled in real-time	Participant #
Delay amount	P1
Delay time	P2
Pitch shifter	P9

Table 15 Effect/parameter controlled in real-time (Table by author).

The primary way of controlling these effects is via expression pedals.

P5 stands out as far as usage of real-time control is concerned: he controls a multitude of (complex) effect parameters via expression pedals and/or tablet or controller. This appears to be common in the musical genre of experimental, improvised music.

A lot of participants (P3, P4, P6, P7, P8 and P9) do not use an expression pedal. Nevertheless, the majority (P1, P2, P4, P5, P6, P8 and P9) still use a Wah-Wah pedal which makes the Wah-Wah effect the most used effect that is controlled in real-time.

Only P3 neither uses an expression pedal nor a Wah-Wah pedal.

9.3.4. Summary of C4

The analysis shows that effects controlling while playing guitar during a live performance is perceived as a challenge by most participants. Correspondingly, active effects controlling done by participants is usually limited to activating and disactivating effects during the song as needed. Despite difficulties, effects controlling while playing appears to be necessary as the rhythm guitar sound differs from the lead guitar sound in the case of every participant and there are also other situations where guitar players may need two (or more) different sounds for one song. Apart from turning effects on and off, many participants state that they do not change individual effect parameters while playing. Additionally, real-time control of effects is not common with the exception being the Wah-Wah effect. These results suggest that effects control while guitar playing currently poses a challenge for guitarists, preventing them from performing more advanced effects controlling than just turning effects on or off.

9.4. C5: Technical integration left-hand setup

This category summarizes the interviewees' impressions as well as observations of the author regarding the technical integration of the left-hand setup.

9.4.1. C5: Observations

First of all, the left-hand setup proved its road-suitability to a large extent. It withstood the stresses of transportation to various locations in Graz und surrounding areas (2x Weiz, 1x Hart bei Graz) by car or on foot without suffering major breakdowns. Between the 3rd and 4th interview, the battery mount holding the 9 V battery in the Mothership broke loose, severing the connection with the ON/OFF switch in the process. However, the cable was resoldered to the switch and the battery mount reinforced. No other technical issues were recorded during the remaining interviews and the left-hand setup functioned at full capacity during all interviews.

Regarding battery life, the 9 V battery powering the buffer/splitter and mixer components of the Mothership lasted throughout all nine interviews and brief checks done by the author before each interview. However, the three AA batteries powering the ESP32, digital potentiometer, OLED display and mechanical potentiometer had to be changed frequently throughout the "interview-month", because they kept losing the necessary voltage rather quickly.

Regarding actual setup integration, the left-hand setup worked in conjuncture with the setups of all guitarists interviewed. In all interviews, it was tested with at least two effects pedals belonging to the respective guitarists.

Furthermore, the Scout fitted on all Fender Stratocaster and Gibson (Les Paul/SG) headstocks played by the interviewed guitarists, fulfilling its design goal. Apart from the headstocks it was designed for, the Scout also proved to work with two Fender Telecasters, an ESP LTD and another electric guitar whose brand is unknown to the author.

9.4.2. C5: Interview results

The study results show that the left-hand setup can be reasonably used in conjuncture with a multitude of effects (pedals) with P3 and P6 even thinking that it works together with all effects (pedals).

P1, P6 and P7 state that the left-hand setup is well suited for the switch between rhythm and lead sounds. Moreover, other exemplary applications mentioned include the possibility to access different rhythm sounds (P7, P8) as well as different degrees of distortion (P8).

Furthermore, P5 notes that it makes sense to adapt the choice of effects used to the respective regions of the fretboard lying either below or above the fret threshold. He goes on to suggest using distortion or delay for the upper fretboard region and phaser, chorus or octave pedal (for basslines) for the lower fretboard region below the fret threshold.

According to P4, the left-hand setup generally makes sense in conjuncture with effects that change the sound only marginally as opposed to effects that drastically alter the guitar signal such as a feedback generator.

The effects listed in Tab. 16 are explicitly cited to work well with the left-hand setup:

Effects working with the left-hand setup	Mentioned by Participant #
Overdrive/distortion	P2, P3, P5, P8
Delay	P2, P3, P4, P5
Chorus	P4, P5, P7
Reverb	P4, P7
Equalizer	P4
Compressor	P4
Phaser	P5
Octave pedal	P5

Table 16 Effects working with the left-hand setup (Table by author).

9.5. C6: Musical integration left-hand setup

The following category covers the participants' impressions and experiences regarding the musical integration and influence of the left-hand setup. Additionally, the author's observations during the test sessions are summarized.

9.5.1. C6: Interview results

According to the guitar players interviewed, the left-hand setup has a major influence on guitar playing containing positive as well as negative aspects.

According to P2, P4, P6 and P7 the left-hand setup facilitates controlling effects as well as the switch between rhythm and solo sounds because players do not need to manually stomp onto effects pedals to activate or disactivate them. P5 also states that the left-hand setup may act as an alternative or substitute to turning pedals on or off by stepping on them with a foot.

A lot of participants state that the left-hand setup also is more than just a substitute:

P5, for instance, believes that the left-hand setup represents a new way of controlling effects, breaking with the traditional school of thought. P5 and P7 state that the left-hand setup opens up new possibilities for playing guitar.

P7 and P8 say that the left-hand setup is in itself an instrument or effect device. P5 states that the left-hand setup basically transforms the guitar into two instruments in one and P9 links it to the functionality of a split keyboard.

According to P4 and P8, the left-hand setup promotes creative playing techniques and styles and provides guitar players with a new perspective and approach to effects control. Furthermore, P4 continues to say that the left-hand setup influences guitar playing as switching to the upper region of the fretboard does now not only mean higher notes but also another kind of sound. P3 also thinks that guitar players then adapt their fretboard movements to integrate this feature into their playing.

P4 and P8 state that the left-hand setup would motivate them to write new songs that are specifically suited to the left-hand setup and thus leveraging its capabilities.

P4 mentions the intuitiveness of the left-hand setup but P5 also states that handling the setup needs some practice.

At the same time, negative aspects of the left-hand setup were also noted by participants.

Some participating guitar players (P2, P3, P8) feel that the left-hand setup is restricting their movements along the fretboard which negatively impacts their playing. Especially the restricted tonal range available for solos bothers players.

Additionally, P1 and P6 note that the left-hand setup requires the players to think more closely about the song structure and associated fret movements prior to playing, and different fingering of chords may be necessary to avoid switching sounds at the wrong time.

In this context, some participants (P6, P8) state that they would prefer the traditional way of switching effects pedals by foot and have no fretboard limitations than using the left-hand setup just to switch between effects.

Furthermore, P7 and P9 believe that the left-hand setup is difficult to integrate into existing songs (and their structures). P6 says that the left-hand setup needs to be already part of the composition process to really make it work and P9 also says that it needs specifically written songs.

Finally, the left-hand setup's applicability is dependent on the musical genres played. There are contradictory opinions on this subject, however. According to P3, jazz is said to be rather unsuitable for the left-hand setup as there are not that many effects employed to begin with. The left-hand setup, thus, tends to add more complexity than solving problems associated with effects control. P4, however, thinks that the left-hand setup is suited for jazz as well as blues. Punk or black metal are cited to be not ideally suited for the left-hand setup's capabilities according to P4. P9 goes on to state that the left-hand setup may be appropriate for experimental music only.

9.5.2. C6: Observations

In general, it can be said that all participants quickly understood the basic working principle of the left-hand setup. When trying it out for the first time, many participants appeared to be astonished that they could switch the guitar sound according to the fret they are playing, exclaiming phrases such as “Oh, that's interesting” or “Ha-ha – that's fun!”.

While the basics were grasped pretty quickly and several chord changes and corresponding sound switches were performed, some participants (P2, P3 and P9) then seemed to be either not willing or not entirely capable of coming up with more advanced uses for the left-hand setup. P9 asked the author to take over the guitar to demonstrate what could be done with the left-hand setup. P3 proceeded to play a memorized (jazz) musical piece without really trying to incorporate the left-hand setup into the guitar playing. P2, albeit being impressed that the setup worked, quickly dismissed the concept, preferring a footswitch instead.

All the other participants (P1, P4, P5, P6, P7 and P8), however, proceeded to an experimental phase during the test sessions in which they tried to come up with interesting and reasonable applications of the left-hand setup within their respective playing styles. For instance, P1, coming from blues, tried to leverage the sound switching capabilities by changing between chords and blues licks while the punk playing P4 experimented with emphasizing different chords by playing them in the higher and different sounding region of the fretboard. During these test sessions, several different effects pedals and combinations were tried out. P8 even asked the author to make a video on his phone in which the participant quickly explained the left-hand setup in his own words and subsequently played a brief musical passage he had come up with.

The musical genres primarily played by the guitarists do not seem to be significant to the different uptakes of the left-hand setup. Two participants (P1 and P2) come from blues rock for example, and P1 seemed to like the left-hand setup and experimented with it while P2 did not. Similarly, P8, who plays mainly rock, was the one asking for the video to be taken while P9, who also plays rock music, was the one asking for inspiration on how the left-hand setup should be used.

It appears that these differences in approaches towards the left-hand setup are not the result of varying guitar skills or musical genres but can rather be attributed to the individual mindsets of the guitarists and their openness for new sound tools and experimentation.

9.5.3. C6: Advantages and disadvantages of the left-hand setup

In general, the following advantages and disadvantages regarding the left-hand setup have been made out by the participants:

Advantages of the left-hand setup:

- More independence (P1)
- Less concentration on effects controlling necessary (P1, P4, P5 and P6)
- More freedom of movement on stage (P4, P6 and P7)

- No necessity to make constructional changes to the electric guitar; easy application (P5)
- Integrability into a conventional setup (P5)
- Relatively simple handling (no special technical knowledge needed) (P5)
- New possibilities for music composition (P5)

Disadvantages of the left-hand setup:

- No reasonable substitute for (effect pedal) switch (P2)
- Restrictive (P2)
- The Scout component is too heavy; may be distracting (P3 P7 and P8)
- Fret detection should go up to 12th fret (P4)
- Hard separation between the two fretboard regions (P5 and P6)
- Song structure must be thought through in advance (P6)
- Difficult to implement into existing songs (P6)

P5 summarizes his impression of the left-hand setup as follows: “You win two instruments but lose some of the tonal range of each instrument”.

Four participants (P1, P4, P5 and P8) state that they would be able to integrate the left-hand setup and would use it during a live performance.

P6 states that he would be able to integrate the left-hand setup but would not use it during a live performance.

P7 states that he would use the left-hand setup during a live performance but is not sure how well it would integrate into his current setup.

Three participants (P2, P3 and P9) state that they would not integrate the left-hand setup and would not use it during a live performance.

9.6. C7: Potential improvement left-hand setup

The following potential improvements were suggested by participants:

First of all, P1, P2, P3, P8 and P9 note that the left-hand setup should be smaller and lighter with participants usually referring to the Scout component. Moreover, the Scout should be more easily attachable to the headstock according to P7 and P9. An often-mentioned reference regarding optimal size, format and attachment mechanism is the clip-on tuner (P5, P7, P8, P9).

In contrast, P4 and P5 also state that the weight of the Scout does not bother them.

Another issue, addressed by P5, P6 and P7, is the latency when switching between the FX loops which should be shorter (and not noticeable). P3 also notes the quiet click when switching.

P6 feels that the Scout was positioned too closely to the first fret and suggested moving it up the headstock.

Suggestions concerning improvement of functionality include:

The fret threshold of the left-hand setup should only be the trigger for the solo and, once above the threshold, the guitar player should be able to solo all over the fretboard until she or he plays more than one string (a chord) or performs a certain gesture signaling the left-hand setup to switch back to the rhythm sound (Suggestion by P1).

Another suggestion is to increase the flexibility of the fret threshold by making it adjustable via an expression pedal. Additionally, the Mothership should come with a bigger, color display that changes color according to activated FX loop (Suggestion by P1).

Another addition to the left-hand setup could be that it differentiates not only between frets but also strings (Suggestion by P5).

Another idea mentioned is that the left-hand setup could not only switch completely between FX loop 1 and 2 but also provide the possibility to blend between FX loops as well (Suggestion by P8).

Furthermore, the aesthetics of the left-hand setup were commented on, stating that it should be less obvious or visible. This is extremely important in some genres such as punk (Suggestion by P4).

9.7. C8: Technical integration right-hand setup

This category summarizes the interviewees' impressions as well as observations of the author regarding the technical integration of the right-hand setup.

9.7.1. C8: Observations

Just like the left-hand setup, the right-hand setup proved to be sturdy and durable enough to withstand transportation to the various interview locations. In contrast to the left-hand setup, no technical issues were encountered at all throughout all nine interviews.

Regarding battery life, the Expressionist was supplied with a power bank that was charged twice during the “interview-month” with the second charge being done solely for precautionary reasons rather than being necessary. Initially conceived to be powered by three AA batteries, the Expressor was powered via a long USB cable for most interviews due to the poor battery life experienced with the left-hand setup. Thus, batteries and money were saved.

A lot of participants (P1, P2, P5, P6, P7 and P9) possess at least one effect pedal with an expression pedal input however, said effect pedal was not always part of the current live guitar setup used during the interviews. Accordingly, the right-hand setup could not always be used in conjuncture with the interviewees’ setups. In those cases, the interviewees tested the right-hand setup using the EHX “The Worm” Wah-Wah, Boss PS-6 Pitch-Shifter and Boss DD-8 delay brought along by the author. Apart from these effects pedals, the right-hand setup was also tested with the Moog MF-Drive (overdrive with Moog filter) and the Strymon Mobius (modulation effects pedal) provided by P7 and P1, respectively.

The Expressor was flexible enough to fit the hands and lower arms of all guitar players interviewed. Note that all guitar players were right-handed so it could not be tested if the Expressor would work with left-handed guitarists as well.

9.7.2. C8: Interview results

According to the statements of the participants, the right-hand setup works well with a lot of effects (pedals). Nevertheless, opinions differ regarding which effects work well and which do not.

P1, P5 and P6 state that the right-hand setup is suited for practically all effects. According to P5, the control possibilities are not restricted to effects pedals only but may be used to control all kinds of devices with a control input.

P1, P2, P3, P5, P8 and P9 say that the right-hand setup works very well in conjuncture with the Wah-Wah effect and that it is a very reasonable option to control this effect. Additionally, P8 notes that other filter-type effects such as the Moog MF-Drive can also be controlled well with the right-hand setup.

P1, P2, P4 and P5 state that the right-hand setup is suitable for modulation effects which include tremolo, chorus and flanger. Moreover, P4 believes that effects that show their potential while playing slower parts are said to be especially suitable for the right-hand setup. P8 also mentions these "ambiance" effects.

P2, P5, P6 and P7 also mention some of these effects such as delay or reverb for instance.

On that note, the shimmer-delay setting on the Boss DD-8 delay pedal controlled by the right-hand setup was particularly well received by P7.

Apart from modulation and ambiance effects, it was also noted that volume modulation (P6), booster (P4) and amount of distortion (P6) could work well with the right-hand setup.

P5 also states that the right-hand setup works well in experimental settings, for example when controlling a pitch shifter and/or feedback modulation.

The effects listed in Tab. 17 are explicitly cited to work well with the right-hand setup:

Effects working with the right-hand setup	Mentioned by Participant #
Filter-type effects such as Wah-Wah	P1, P2, P3, P5, P8, P9
Reverb	P2, P5, P6, P7, P8
Delay	P2, P5, P6, P7, P8
Modulation effects such as tremolo, chorus and flanger	P1, P2, P4, P5
All effects	P1, P5, P6
Distortion	P6
Volume modulation	P6
Booster	P4
Pitch Shifter	P5
Feedback modulation	P5

Table 17 Effects working with the right-hand setup (Table by author).

While a lot of participants cite the above-mentioned effects as suitable for the right-hand setup, there are also those that deem reverb (P3), delay amount

(P3 and P9) and delay time (P1), and overdrive (P3) as inappropriate for the right-hand setup control possibilities.

9.8. C9: Musical integration right-hand setup

This category is dedicated to the participants' impressions and experiences regarding the musical integration and influence of the right-hand setup. Additionally, the author's observations during the test sessions are summarized.

9.8.1. C9: Interview results

There are positive as well as negative opinions regarding the right-hand setup that differ from participant to participant.

According to P1, P2, P3, P4, P5, P6 and P7, the control possibilities of the right-hand setup are described as being simpler, more free, natural and delicate as well as more expressive in comparison to those offered by an expression pedal. P5 explicitly states that the right-hand setup could be a substitute for an expression pedal.

The handling and control of the Wah-Wah effect via the right-hand setup received particularly positive feedback:

The control of the Wah-Wah effect via the right-hand setup is described as easier because by using the right-hand setup, guitar players are automatically in time (according to P2) and are not forced to concentrate on being on time, thereby relieving them from cognitive load while playing (according to P3).

Furthermore, P3 states that when using the Wah-Wah effect, the right-hand setup completely integrates into conventional playing techniques.

Moreover, P5 also describes the right-hand setup/Wah-Wah combination as being the better Auto-Wah. Sometimes the tempo of a song is too fast and Wah-Wah control by foot is no longer possible. Here, guitar players tend to use an Auto-Wah. The right-hand setup/Wah-Wah combination however is said to be better because it can be played in high tempo songs (because the hand moves sufficiently fast) and, at the same time, it simultaneously provides more control possibilities than an Auto-Wah.

P4 also favorably notes that by using the right-hand setup, he can wear heavy boots without worrying about having no feel in the foot.

Apart from the Wah-Wah effect, the right-hand setup is described as having other positive aspects as well.

According to P4, P5, and P7, the right-hand setup promotes creativity, widens the creative horizon, and opens new possibilities. P4 further notes that it encourages the use of effects because effects control is facilitated. P6 also adds that the right-hand setup stimulates new (songwriting) ideas.

Beyond that, P5 states that the right-hand setup enables effects to dynamically adapt to the aspects of the current playing style (for example the tempo), resulting in less need to change settings manually. P6 also states that the right-hand setup adjusts itself and the effects to the groove of the song and hence, expressivity is promoted.

According to P1 and P5, works well in ambient pieces because then, the playing style is adapted to play longer, sustained notes or chords which can then be modulated by the right-hand movements.

Another positive feature noted by P5 is that the right-hand setup makes effects control more visible and comprehensible for an audience. The right-hand setup may encourage guitar players to move in a more expressive way on stage.

Two participants (P6 and P7) specifically mention that it is fun to use the right-hand setup, which they deem a very important feature. Another participant (P1) talks about love at first sight after using the right-hand setup for the first time.

P6 states that, apart from the live application, he primarily thinks the right-hand setup to be a fine tool within the studio environment.

Nevertheless, while increased intuitiveness is mentioned, P1, P5 and P7 are also of the opinion that the hand movements necessary go beyond those one is accustomed to and hence, proper handling must also be learnt.

Although there are many positive impressions, participants also noted some shortcomings concerning the right-hand setup.

It is noted by P5 that many guitarists are already very used to controlling the Wah-Wah via foot movements and may therefore be reluctant to learn a new method.

Another issue raised by P7 and P9 is that the right-hand setup cannot entirely replace an expression pedal. Otherwise, conventional playing styles would have to be significantly altered, which some guitarists are not prepared to do.

Additionally, P7, P8 and P9 state they find it easier to play in time with an expression pedal and say that they still prefer expression pedals for some features also because their hands remain free to play the guitar exclusively.

P9 in particular states that he perceives the right-hand setup as a limitation because it essentially takes away one control parameter, namely the foot.

Some participants (P1, P4, P7 and P8) are of the opinion that the right-hand setup is suitable for niche applications and should be used for specific situations like an effect.

P4 notes that the right-hand setup is not very suitable for punk music and here only suited for experimental song passages.

P3 states that the right-hand setup works great in funk music but not jazz.

P7, coming from classical guitar, notes that for fingerstyle techniques, the right-hand setup is not suitable as the hand is not moved enough to make effects control possible.

Regarding the different data type settings of the right-hand setup tested during the interviews the following information was obtained:

- The gyroscope setting has very useful applications (P7).
- While using the Wah-Wah effect, no significant difference was found between gyroscope and raw accelerometer data (P3).
- The applicability of the processed accelerometer data depends on the setup used (P7).
- The processed accelerometer setting would have made more sense if the mapping had been flipped, at least in conjuncture with delay (P7, P8).

9.8.2. C9: Observations

While most participants quickly understood the basic working principles of the right-hand setup, more explanations of how to handle it better were necessary compared to the left-hand setup. Participants tended to understand the gyroscope setting better than the accelerometer setting and often performed the sweeping movements associated with the gyroscope setting even when in accelerometer mode. Additionally, many participants exaggerated the hand movements especially in the beginning before realizing that “normal” strumming movements are enough to trigger and modulate effects.

The favorable attitude of participants towards the right-hand setup/Wah-Wah effect combination mentioned above could already be observed during the test sessions as well. All participants immediately understood how to control the Wah-Wah effect via the right-hand setup, undermining its intuitiveness.

While the right-hand setup/Wah-Wah combination was universally liked by the participants, the usage of other effects was often received with mixed emotions. Several participants liked the delay effect with the right-hand setup set to accelerometer mode but P7 and P8 noted that they would have preferred a reversed mapping. Moreover, the accelerometer setting increasing and decreasing the effect amount according to strumming intensity proved to be a little less intuitive than the Wah-Wah effect, but guitarists adapted to it over time.

Guitar players accomplished at funky as well as strumming-focused playing styles could get more out of the right-hand setup as these styles emphasize the strumming movements resulting in ample effects modulation possibilities. In contrast, P7 who likes to play fingerstyle quickly noticed that here the right-hand setup is not really applicable.

As was the case with the left-hand setup tests, some participants (P2, P3 and P9) stopped coming up with new applications for the right-hand setup quickly after testing the Wah-Wah effect while others (P1, P4, P5, P6, P7 and P8) proceeded to explore several other effects and tried to come up with different musical passages that make use of the right-hand setup’s capabilities, often resulting in ambience sounds.

However, it must be stated that in some cases a lack of experimenting during test sessions could also have been the result of a lack of guitar effects pedals with expression input available to the interviewee and author.

Again, different musical backgrounds did not appear to be the deciding factor in the uptake of the right-hand setup. Instead, the guitarists' behavior towards the right-hand setup largely mirrored that towards the left-hand setup with guitarists usually being receptive to both setups or neither setup. Here, the exception is the Wah-Wah effect which, as stated before, could be applied by all participants and lead to the right-hand setup getting more favorable reviews than the left-hand setup in the end.

9.8.3. C9: Advantages and disadvantages of the right-hand setup

To sum it up, the following advantages and disadvantages regarding the right-hand setup have been made out by the participants:

Advantages of the right-hand setup:

- Possible substitute to an expression pedal (P2)
- Enables more natural control of the Wah-Wah effect (P3)
- Ensures that guitarists are always in time when playing the Wah-Wah effect (P2)
- Enables more independence and freedom of movement on stage (P2)
- Relieves guitarists of cognitive load (P4)
- Access to new modulation possibilities (P5)
- Enables more expressivity and musicality in effects control (P6)
- Visible effects control for audience (P5)
- Integrability in conventional playing styles possible (P5)
- Integrability in commercial setups (P5)
- Easy installation (easier than left-hand setup) (P5)

Disadvantages of the right-hand setup:

- Hand strap attachment of the Expressor perceived as annoying (P3, P9)
- Putting on the Expressor is time-consuming (P4)
- Aesthetics of right-hand setup (P4)
- Right hand setup is too visible (P4)

- Right hand setup restricts palm-muting technique (P4)

According to P7, an advantage that can simultaneously be a disadvantage is that the playing style must be adapted to the right-hand setup.

Seven participants (P1, P2, P4, P5, P6, P7 and P8) state that they would be able to integrate the right-hand setup and would use it during a live performance.

P6 adds that he would use the right-hand setup in the studio as well.

Two participants (P3 and P9) state that they would neither integrate the right-hand setup nor use it during a live performance.

As mentioned in chapter 7.6.2, the option to select between orientation data and processed (as opposed to “raw”) linear acceleration data was added to the right-hand setup in-between interviews. Accordingly, P1, P2, P3, P4 and P5 tested the right-hand setup with the two data options “raw” orientation data and “raw” linear acceleration data while P6, P7, P8 and P9 tested the options “raw” orientation data and processed linear acceleration data. Nevertheless, it was not deemed necessary to divide the answers of participants as the statements are formulated quite generally and reflect the overall impressions of the right-hand setup.

9.9. C10: Potential improvement right-hand setup

The following potential improvements were suggested by participants:

Improvement suggestions are largely concerned with the attachment and aesthetics of the Expressor.

P1, P2 P3, P5 mostly agree that the right-hand setup, in particular the Expressor, should be smaller and lighter to the point where it is not noticeable anymore. P1 suggests the dimensions of an EBow as reference.

P3 notes that particularly the strap running over the back of the hand should be thinner, so palm-muting is not impaired.

P7 and P8 suggest that the Expressor should be easier to put on with references being a glove or a ring.

According to P1, the Expressor should not have a slider or pressure button to power it on or off. Otherwise, guitarists may easily turn it on or off by accident as they move their hand while playing.

As was the case with the left-hand setup, P4 states that the right-hand setup is too visible, especially for genres like punk or black metal.

P5, in contrast, was not bothered by the size and visibility of the Expressor. In fact, he stated that small things are often not seen by the audience rendering effects control non-transparent.

Apart from attachment and aesthetics there was also a technical improvement suggestion:

The range of hand movement should be adaptable or calibratable in order to better fit the individual needs of each guitarist (Suggestion by P8).

10. Summary of findings

This chapter provides a general overview concerning the participants' feedback towards Dextoria and, subsequently, relates the findings of the expert interviews and usability test to the four objectives of the research hypothesis.

The general feedback of the participants towards Dextoria is quite positive:

The right-hand setup was especially well received by participants with a total of seven stating that they would be able to integrate the right-hand setup and would use it during a live performance.

The reviews for the left-hand setup were a bit more diverse with a total of four participants stating that they would be able to integrate the left-hand setup and would use it during a live performance. Furthermore, one participant stated that he would be able to integrate the left-hand setup but would not use it during a live performance and one participant stated that he would use the left-hand setup during a live performance but is not sure how well it would integrate into his current setup.

The right-hand setup was dismissed by two participants and the left-hand setup by three participants, all of them stating that they would neither integrate the setups nor use them during a live performance.

As already touched upon during the presentation of the empirical findings, there appears to be no definite connection between musical genre and uptake of the setups – at least for the limited sample of guitarists taking part in the study – with guitarists sharing the same musical backgrounds sometimes taking on different stances regarding the setups. It appears that these differences in approaches towards Dextoria can rather be attributed to the individual mindsets of the guitarists and their openness for new sound tools and experimentation.

10.1. Ecological validity in terms of live performance setup

Taking into account the relevant theoretical findings as well as the results of the empirical study, it can be concluded that both, the left- and right-hand setup of the Dextoria system are to a great extent ecologically valid in terms of the live performance setup of guitarists.

The theoretical findings suggest that guitarists tend to use a signal chain consisting of electric guitar(s), effects pedals and amplifier(s) with many kinds of different effects pedals involved. These findings were confirmed by the empirical study where the guitar setups of the participants corresponded to the above-mentioned signal chain. Another important finding is that guitarists usually do not use computers and/or digital effects running on computers in their live setup. Hence, a system that seeks to integrate into this environment should be able to work alongside the signal chain components electric guitar (especially headstocks), amplifier as well as various effects pedals with no computer being required.

During the test session of the empirical study, the left- and right-hand setup fulfilled these premises. The left-hand setup worked alongside all of the participants' setups and the Scout component could be fitted on the electric guitar of each participant. Albeit not all of the participants had effects pedals with expression input at their disposal, the right-hand setup could still be integrated in the setup using effects brought along by the author and it worked in the cases where participants had their own suitable effects pedals. Furthermore, the Expressor fit onto the arms and hands of all guitarists. It was positively emphasized that no constructional changes to the electric guitar are necessary and the relatively simple handling that does not require any special technical knowledge was highlighted. Finally, a major contributing factor to the integrability of Dextoria is that it does not rely on computers or digital effects which makes Dextoria superior in this regard to other guitar augmentation projects mentioned in the beginning.

Negatively impacting technical integrability of both setups are constructional shortcomings such as the Scout being too heavy or the Expressor being a little cumbersome to put on.

10.2. Ecological validity in terms of conventional playing techniques

As far as the ecological validity in terms of conventional playing techniques is concerned, the setups of the Dextoria system were partially successful.

With regards to the basic playing techniques mentioned in Ch. 6.2., both the left- and right-hand setups largely proved to be ecologically valid. The left-hand setup did not provide any obstacle to playing techniques during the test sessions. The right-hand setup led to a reduced ability to palm mute due to the attachment device wrapping around the hand but did otherwise not interfere.

The left-hand setup revealed shortcomings as far as its integrability into the structure of existing songs is concerned, negatively impacting its practical application. The concerns mentioned in the theoretical part about the left-hand setup needing a clear-cut separation between rhythm and lead guitar parts regarding their fretboard positions were confirmed during the empirical study. Some of the participating guitarists felt restricted in their fretting hand movements. Especially the reduced tonal range of guitar solos bothered the players, stating that they prefer to have the whole fretboard at their disposal for soloing.

In this context, the right-hand setup fared better than its counterpart. For example, the right-hand setup/Wah-Wah effect combination is cited to integrate completely into typical playing styles associated with the Wah-Wah effect. Furthermore, the study revealed the Wah-Wah effect to be the most common (and oftentimes only used) real-time effect among participants which makes it even more important that the right-hand setup works well in controlling it. Apart from the Wah-Wah effect, the right-hand setup works together with various other effects such as ambient (reverb/delay) or modulation effects. Sustained, slower playing styles are promoted because notes and chords can then be modulated by the right-hand movements.

10.3. Relief from additional cognitive load associated with controlling effects

To begin, the empirical study revealed that effects control while playing guitar is perceived as a challenge by guitarists because both hands are usually involved in playing the guitar, the effects devices are physically difficult to reach, and it is generally perceived as being distracting. Consequently, effects control while playing is limited: most settings are done prior to playing and a large part of effects controlling consists of just turning effects on or off with individual parameters readjusted only if acutely necessary. Moreover, apart from experimental music, real-time control of effects is not that common with it being too big of a challenge cited as a reason. These results suggest that effects control in guitar playing is currently not optimal and puts cognitive load onto guitarists, thereby justifying Dextoria's quest to simplify effects control.

The test sessions showed that the right-hand setup partially succeeds in this quest of facilitating effects control. While the Wah-Wah effect is especially cited to be easier to control, the right-hand setup generally encourages the use of effects because effects control is facilitated. However, for a few participants, expression pedals are still preferred for some features because guitar players' hands remain free to play the guitar exclusively.

According to participants, the left-hand setup also facilitates controlling effects in general as well as switching between rhythm and lead guitar sounds because players do not need to manually stomp onto effects pedals to activate or disactivate them. At the same time, however, some participants said that considering the downsides that come with the left-hand setup, they would prefer the traditional way of switching effects pedals by foot and have no fretboard limitations than using the left-hand setup just to switch between effects.

10.4. Possibility of a smoother and more flexible performance

With regards to the last objective of the research hypothesis, both setups took some steps in the right direction.

For instance, by controlling effects via the right-hand setup, the act of controlling becomes more visible for the audience, making guitar players' control movements on stage more comprehensible and expressive. Additionally, the right-hand setup is quoted to provide guitarists with more independence and freedom of movement on stage since they do not have to remain in front of their pedalboard all the time. Furthermore, effects control via the right-hand setup is described as simpler, more free, natural, and delicate as well as more expressive in comparison to expression pedals. Beyond that, the right-hand setup enables effects to dynamically adapt to the aspects of the current playing style (for example the tempo), resulting in less need to change settings manually. The left-hand setup also promotes greater independence and freedom of movement on stage as effects control can happen independently from where players are standing and not just in front of the pedalboard.

Naturally, the facilitation of effects control, mentioned in Ch. 10.3. above, also promotes smoother performance.

With regards to the design goal of intimacy mentioned in Ch. 4.2., both setups proved to be intuitive enough so that all participants understood the basic handling of the setups almost immediately. Additionally, almost everyone could come up with some musical passages involving the setups' capabilities in the short amount of time during the test sessions. However, some practice is said to be necessary for more advanced techniques.

10.5. Miscellaneous findings

While the two setups achieved the goals mandated by the research hypothesis to a large extent, it can be acknowledged that the setups slightly overshot their objectives. The left-hand setup was basically conceived as a substitute for activating and disactivating effects pedals by foot and the right-hand setup as a substitute for an expression or Wah-Wah pedal.

However, several participants mentioned during the test sessions that the setups are less of a substitute as they are a completely new way of controlling effects. The left-hand setup in particular was cited to be more of a new instrument or effect device in itself basically transforming the guitar into two instruments in one. The right-hand setup, on the other hand, gives players access to new modulation possibilities and provides them with more expressivity and musicality in effects control. Both setups promote creative playing techniques and styles and provide guitar players with a new perspective and approach to effects control. This leads participants to be motivated to write new songs that leverage the setup’s capabilities.

11. Conclusion

Ultimately, it can be concluded that the Dextoria system with its left- and right-hand setups managed to fulfill a lot of the objectives set out to achieve.

The results of the expert interviews strengthened the use case for the Dextoria system: Firstly, the absence of computers in conventional guitar live setups was confirmed. Moreover, the results showed that effects control while playing is perceived as a challenge by guitarists. Guitarists usually only engage in limited effects control while playing guitar (e.g., turn effects on/off) instead of performing more advanced methods such as altering individual parameters or real-time control.

The usability test proved the Dextoria system to be ecologically valid in terms of live performance setup with both hands’ setups integrating into participants’ setups. Neither component substantially hampered conventional playing techniques, however, the left-hand setup appears somewhat restrictive regarding the access to possible fret positions. Both setups succeeded in facilitating effects control for guitarists, nevertheless, it was also found that the right-hand setup cannot completely substitute all expression pedal functions and the left-hand setup’s fretboard limitations may cancel out its benefits in some cases. Finally, the Dextoria system was found to contribute to a smoother and more flexible performance by making effects control more natural, visible, dynamic, and expressive as well as promoting freedom of movement on stage.

Apart from the research objectives, the Dextoria system was also determined to be a new way of controlling effects with both setups promoting creative playing techniques/styles and providing guitar players with a new perspective and approach to effects control.

12. Further research

The empirical study revealed several suggestions for improvement as well as helpful feedback regarding the further development of the Dextoria system. Some suggestions were implemented for the appended demonstration videos. For example, these improvements include a reversed mapping for the right-hand setup and the use of lithium instead of alkaline AA batteries for the left-hand setup. The implementation of most other suggestions was out of scope of this Master's thesis. Especially the suggested constructional changes involving a drastic decrease in size and weight of components are difficult to achieve without substantial time and monetary resources allocated to the project. Further research regarding this topic could involve further development of the Dextoria system, incorporating the feedback and suggestions received.

Such a "Dextoria 2.0" could, for example, include a reduction in the size of the Scout and the Expressor as well as easier attachment mechanisms for both components. This would, on one hand, increase the usability and, on the other hand, render the two components' appearance less technical and more subtle, thus increasing the acceptance of Dextoria among conventional guitarists. Regarding the left-hand setup, a solution to address the fretboard limitations must be found or it must be marketed as its own effect device. Either way, it has a lot of potential from a creative perspective, especially when incorporated in the composing process from the start. The functionality of the left-hand setup could be advanced by additionally providing the possibility to blend between the two FX loops instead of hard switching between the two of them.

Apart from technical advancements, the qualitative research conducted could be complemented by quantitative research involving a greater sample of guitarists to be able to draw more general conclusions and thus, concentrate development efforts on the aspects that matter most to electric guitarists.

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14. Appendix

The appendix includes the interview guideline, translated into English, and the summarized spreadsheets of the qualitative content analysis.

14.1. Interview guideline

Interview guideline regarding the ecology of guitarists (12 questions)

Background of interviewee (2 questions)

1. Personal questions
    1.1. Age
    1.2. Gender
    1.3. Level of experience
        1.3.1. How many years have you been playing guitar?
        1.3.2. How many years have you been performing on stage?
        1.3.3. Average number of gigs per year?
        1.3.4. Typical performance locations?
        1.3.5. National and/or international?
2. Which genres do you play live the most?

General information about the live performance setup (1 question)

3. How does your current live performance setup look like?
    3.1. Signal Chain in general
        3.1.1. Amplifier
        3.1.2. Effect pedals (yes/no? + which? + how many?)
    3.2. Computer/interface?
    3.3. Other special features?

Control of effects while playing (2 questions)

4. How do you handle the control of effects while performing and especially while playing guitar?
5. What are the challenges and/or difficulties in controlling effects while playing guitar?

Control of effects while playing; focus left-hand setup (4 questions)

6. How does your rhythm sound differ from your solo sound?

7. How do you act when you have to switch between rhythm sound and solo sound in a live context, and how do you feel about this switch?
8. From which fret on do you play solos on average? Up to which fret do you play rhythm? Is it possible to make such a clear distinction here?
9. Are there other situations where you need two different types of sounds?

Control of effects while playing; focus right-hand setup (2 questions)

10. How important is real-time control over effect parameters while playing to you?
11. Do you use an expression/Wah-Wah pedal or other such effects? Why yes/why not?

Conclusion (1 question)

12. Do you have any additional comments, suggestions, or relevant content to share?

Interview guideline regarding the evaluation of the system (15 questions)

Left-hand setup (7 questions)

1. With which effects did it work well/not so well?
2. How would you describe the control capabilities of the effect you tried using the hand movements? More expressive? More intuitive?
3. How does your guitar playing change when you use the left-hand setup?
4. Please list the advantages and disadvantages of using such a system live for you!
5. How would you describe the degree of integration into your current live setup?
6. Can you imagine using the system live? Why yes/why not?
7. Where do you see potential for improvement?
   - 7.1. Technical nature; examples could be:
     - 7.1.1. More setting possibilities
     - 7.1.2. DRY/WET ratio changeable
     - 7.1.3. More accurate fret detection
     - 7.1.4. Finding the right sensor positioning
   - 7.2. Ergonomic nature

7.3. Musical nature

Right-hand setup (7 questions)

8. With which effects did it work well/not so well?
9. How does your guitar playing change when you use the right-hand setup?
10. How would you describe the control capabilities of the effect you tried using the hand movements? More expressive? More intuitive?
11. Please list the advantages and disadvantages of using such a system live for you!
12. How would you describe the level of integration into your current live setup?
13. Can you imagine using the system live? Why yes/why not?
14. Where do you see potential for improvement?
    14.1. Technical nature
    14.2. Ergonomic nature
        14.2.1. For example: hand-attachment
    14.3. Musical nature

Conclusion (1 question)

15. Do you have any additional comments, suggestions, or relevant content to share?

14.2. Spreadsheets of content analysis

C3: Ecology of guitarists/performance setup
C4: Ecology of guitarists/controlling effects
C5: Technical integration left hand setup
C6: Musical integration left hand setup
C7: Potential improvement left hand setup
C8: Technical integration right hand setup
C9: Musical integration right hand setup
C10: Potential improvement right hand setup

C3: Ecology of guitarists/performance setup

Statements	Total
P1, P2, P3, P4, P6, P7, P8 and P9 use the basic signal chain: electric guitar – effects pedals – guitar amplifier.	8
P1, P2, P3, P4, P5, P6, P7, P8 and P9 use guitar amplifiers as their last element of the signal chain.	8
P5 frequently uses an audio interface and laptop as part of their live performance setup. All other participants do not.	8/1
P1, P3, P6 and P7 state that the live guitar setup should not be complex but rather configured in a straightforward and easy way.	4
P4 and P5 alter their live setup depending on the musical genres played.	2
Sometimes, different effect pedal models/brands are used for the same type of effect; for example, P6 uses one analog delay and one digital delay while P7 uses 2 different overdrives.	2
P2 and P5 also use digital multi-effects pedals.	2
P9 even uses just one modeling amplifier that simultaneously serves as guitar amp and effects processor.	1
P9 states that he has experimented a lot with his setup, trying out various effects and combinations.	1
P5 has a very elaborate setup and even uses two different signal chains simultaneously.	1
P2 uses a multi-effects pedal in combination with (analog) single effects units.	1
P5 states that he would go directly into a PA if using an amplifier was not an option.	1
P5 is the only one to use digital effects running on a computer when performing live.	1

Frequently mentioned effects:

Effect type	Used by participant #	Total
Overdrive	P1, P3, P4, P5, P6, P7, P8, P9	8
Delay	P1, P3, P4, P5, P6, P7, P8	7
Booster	P1, P3, P4, P7, P8	5

Tuner	P1, P4, P6, P7, P8	5
Reverb	P1, P3, P4, P5, P6	5
Wah-Wah	P1, P4, P5, P8	4
Modulation effects (e.g., phaser, flanger) *	P1, P6, P8	3

Less frequently mentioned effects:

Effect type	Used by participant #	Total
Fuzz	P1, P6	2
Distortion	P5, P9	2
Equalizer	P4, P7	2
Tremolo	P5, P6	2
Compressor	P4, P5	2
Multi-effects pedal	P2, P5	2
Noise Gate	P4	1
Feedback Generator	P4	1
Pitch Shifter	P5	1
Filter	P5	1
Ring Modulator	P5	1
Granular Synthesizer	P5	1
Bitcrusher	P5	1
Organ emulator	P8	1
Talk box-style effect	P9	1

C4 Part 1: Ecology of guitarists/controlling effects

Statements	Total
Effects controlling while playing guitar during a live performance is perceived as a challenge by P1, P3, P4, P6, P7, P8 and P9.	7

According to P1, P3, P4, P5, P6, P8 and P9, active effect controlling is usually limited to activating and disactivating effects during the song as needed.	7
Apart from turning effects on and off, P2, P3, P4, P6, P7 and P8 state that they do not change individual effect parameters while playing.	6
According to P2, P3, P4, P6, P7 and P8, the effects settings are adjusted prior to the performance e.g., during soundcheck.	6
P3 states that some effects consistently remain turned on during the performance.	1
P4, P7 and P9 state that, as effects are usually on the ground in front of the player, they are physically difficult to access.	3
P1, P4 and P5 stated that they actively control individual effect parameters while playing.	3
Effects controlling while playing can be distracting according to P8 and P4 adds that it is difficult for guitar players as both their hands are involved in playing the guitar.	2
It is stated by P1 and P3 that effects control is not trivial, instead it must be learnt, and one must get accustomed to controlling effects while playing.	2
P4 and P6 say that they tend to adjust individual effect parameters during performances only if readjustment or correction of settings are acutely necessary.	2
Only P2 explicitly stated that controlling effects is no challenge (for him).	1
P4 states that players run the risk of activating or deactivating effects at the wrong time, for example not on the beat.	1
Especially switching between rhythm and lead sound is cited as challenging by P8.	1
P1 states that effects control must be mentally planned ahead of the song or at least well ahead of changing the sound.	1
P1 states that he sometimes performs up to eight switching acts in one song.	1
P8 may need up to four switching acts to change from rhythm to lead sound.	1
According to P4, whether active effects control while playing is actually desired or not depends on the individual attitude of the guitar player as well as on the musical genre played.	1
P4 says that specifically in punk or black metal, active effects control is not really necessary.	1

Effects that are specifically mentioned when talking about activating and disactivating effects during the song:

Kind of (dis-)activated effect during song	Participant #
Overdrive	P1
Tremolo	P1
Reverb	P4
Delay	P4
Amplifier channel	P4
Preset change (for multi-effects-devices)	P9

Actively control individual effect parameters while playing:

Kind of control for individual parameters	Participant #
Volume control via expression pedal	P2
Delay times via expression pedal	P9
Control of various effect parameters via expression pedal	P5
Control of various effect parameters via extra knob on electric guitar (custom construction)	P5
Control of various effect parameters via TouchOSC (tablet app)	P5

C4 Part 2: Ecology of guitarists/controlling effects; left-hand setup

Statements	Total
In the case of P1, P2, P3, P4, P5, P6, P7, P8 and P9, the rhythm guitar sound differs from the lead guitar sound.	9
P1, P3, P4, P6 and P7 are of the opinion that the lead guitar sound should be similar to the rhythm guitar sound, just louder. To get the desired increase in volume, a booster or a compressor are applied.	5

Apart from different rhythm and lead sounds, P1, P3, P4, P7 and P8 say that there are other situations where guitar players may need two (or more) different sounds for one song.	5
For P2, P8 and P9, the rhythm sound tends to be clean to crunchy with the solo sound not only being louder but also more distorted.	3
In general, P3 and P8 state that they use the whole fretboard for their solos.	2
According to P3, there is no substantial difference between rhythm and lead sound in jazz except the volume.	1
P4 states that solos tend to be short in punk and are even frowned upon resulting in less need for special effects for a solo.	1
P3 uses the volume knob of the guitar to control the volume for lead/rhythm sounds.	1
P5 states that it cannot be precisely stated from which fret number on solos usually take place.	1
P3 says that rhythm parts tend to be played in the lower parts of the fretboard.	1
P4 states that he usually solos from the 12th fret on and never solos below the 7th or 9th fret.	1
P2 states that he exclusively needs one sound.	1
According to P3, different sounds are needed, for example, when cover songs are played.	1
According to P7, different sounds are needed, for example, if individual parts of a song differ substantially from each other.	1
According to P8, different sounds are needed, for example, if fills are frequently intermingled with rhythm guitar parts.	1

Effects used for solos:

Effects used for solos	Participant #
Delay	P2, P8, P9
Reverb	P2, P9
Chorus	P4 (used effect in the past)
Fuzz	P6

C4 Part 3: Ecology of guitarists/controlling effects; right-hand setup

Statements	Total
P1, P2, P4, P5, P6, P8 and P9 use a Wah-Wah pedal.	7
P3, P4, P6, P7, P8 and P9 do not use an expression pedal.	6
P1, P5, P7 deem real-time control important or useful.	3
P2, P3 and P9 explicitly state that for them, real-time control is not relevant.	3
P1 and P4 deem real-time control a great challenge.	2
P4 states that for him playing guitar and controlling effects are perceived as separate tasks.	1
P5 stands out as far as usage of real-time control is concerned: he controls a multitude of (complex) effect parameters via expression pedals and/or tablet or controller. This appears to be common in the musical genre of experimental, improvised music.	1
P3 neither uses an expression pedal nor a Wah-Wah pedal.	1

Effects and parameters that are controlled in real-time:

Effect/parameter controlled in real-time	Participant #
Delay amount	P1
Delay time	P2
Pitch shifter	P9

C5: Technical integration left-hand setup

Statements	Total
P1, P6 and P7 state that the left-hand setup is well suited for the switch between rhythm and lead sounds.	3
P3 and P6 think that the right-hand setup works together with all effects (pedals).	2
According to P7 and P8, other exemplary applications mentioned include the possibility to access different rhythm sounds.	2

According to P8, other exemplary applications mentioned include the possibility to access different degrees of distortion.	1
P5 notes that it makes sense to adapt the choice of effects used to the respective regions of the fretboard lying either below or above the fret threshold. He goes on to suggest using distortion or delay for the upper fretboard region and phaser, chorus or octave pedal (for basslines) for the lower fretboard region below the fret threshold.	1
According to P4, the left-hand setup generally makes sense in conjuncture with effects that change the sound only marginally as opposed to effects that drastically alter the guitar signal such as a feedback generator.	1

The following effects are cited to work well with the left-hand setup:

Effects working with the left-hand setup	Mentioned by Participant #
Overdrive/distortion	P2, P3, P5, P8
Delay	P2, P3, P4, P5
Chorus	P4, P5, P7
Reverb	P4, P7
Equalizer	P4
Compressor	P4
Phaser	P5
Octave pedal	P5

C6: Musical integration left-hand setup

Statements	Total
According to P2, P4, P6 and P7 the left-hand setup facilitates controlling effects as well as the switch between rhythm and solo sounds because players do not need to manually stomp onto effects pedals to activate or disactivate them.	4
P2, P3, P8 feel that the left-hand setup is restricting their movements along the fretboard which negatively impacts their playing. Especially the restricted tonal range available for solos bothers players.	3
P5 and P7 state that the left-hand setup opens new possibilities for playing guitar.	2

P7 and P8 say that the left-hand setup is in itself an instrument or effect device.	2
According to P4 and P8, the left-hand setup promotes creative playing techniques and styles and provides guitar players with a new perspective and approach to effects control.	2
P4 and P8 state that the left-hand setup would motivate them to write new songs that are specifically suited to the left-hand setup and thus leveraging its capabilities.	2
P1 and P6 note that the left-hand setup requires the players to think more closely about the song structure and associated fret movements prior to playing, and different fingering of chords may be necessary to avoid switching sounds at the wrong time.	2
P6 and P8 state that they would prefer the traditional way of switching effects pedals by foot and have no fretboard limitations than using the left-hand setup just to switch between effects.	2
P7 and P9 believe that the left-hand setup is difficult to integrate into existing songs (and their structures).	2
P5 states that the left-hand setup may act as an alternative or substitute to turning pedals on or off by stepping on them with a foot.	1
P5 believes that the left-hand setup represents a new way of controlling effects, breaking with the traditional school of thought.	1
P5 states that the left-hand setup basically transforms the guitar into two instruments in one.	1
P9 links the left-hand setup to the functionality of a split keyboard.	1
P4 says that the left-hand setup influences guitar playing as switching to the upper region of the fretboard does now not only mean higher notes but also another kind of sound.	1
P3thinks that guitar players then adapt their fretboard movements to integrate this feature into their playing.	1
P4 mentions the intuitiveness of the left-hand setup.	1
P5 states that handling the setup needs some practice.	1
P6 says that the left-hand setup needs to be already part of the composition process to really make it work.	1
P9 says that the left-hand setup needs specifically written songs.	1
According to P3, jazz is said to be rather unsuitable for the left-hand setup as there are not that many effects employed to begin with. The left-hand setup, thus, tends to add more complexity than solving problems associated with effects control.	1

P4 thinks that the left-hand setup is suited for jazz as well as blues.	1
Punk or black metal are cited to be not ideally suited for the left-hand setup's capabilities according to P4.	1
P9 states that the left-hand setup may be appropriate for experimental music only.	1

C6: General integration left-hand setup

Statements	Total
Advantage of the left-hand setup: Less concentration on effects controlling necessary (P1, P4, P5 and P6)	4
Four participants (P1, P4, P5 and P8) state that they would be able to integrate the left-hand setup and would use it during a live performance.	4
Advantage of the left-hand setup: More freedom of movement on stage (P4, P6 and P7)	3
Disadvantage of the left-hand setup: The Scout component is too heavy; may be distracting (P3 P7 and P8)	3
Three participants (P2, P3 and P9) state that they would not integrate the left-hand setup and would not use it during a live performance.	3
Disadvantage of the left-hand setup: Hard separation between the two fretboard regions (P5 and P6)	2
Advantage of the left-hand setup: More independence (P1)	1
Advantage of the left-hand setup: No necessity to make constructional changes to the electric guitar; easy application (P5)	1
Advantage of the left-hand setup: Integrability into a conventional setup (P5)	1
Advantage of the left-hand setup: Relatively simple handling (no special technical knowledge needed) (P5)	1
Advantage of the left-hand setup: New possibilities for music composition (P5)	1
No reasonable substitute for (effect pedal) switch (P2)	1
Disadvantage of the left-hand setup: Restrictive (P2)	1
Disadvantage of the left-hand setup: Fret detection should go up to 12th fret (P4)	1

Disadvantage of the left-hand setup: Song structure must be thought through in advance (P6)	1
Disadvantage of the left-hand setup: Difficult to implement into existing songs (P6)	1
P5 summarizes his impression of the left-hand setup as follows: “You win two instruments but lose some of the tonal range of each instrument”.	1
P6 states that he would be able to integrate the left-hand setup but would not use it during a live performance.	1
P7 states that he would use the left-hand setup during a live performance but is not sure how well it would integrate into his current setup.	1

C7: Potential improvement left-hand setup

Statements	Total
P1, P2, P3, P8 and P9 note that the left-hand setup should be smaller and lighter with participants usually referring to the Scout component.	5
P5, P7, P8 and P9 mention a clip-on tuner as reference regarding optimal size, format and attachment mechanism.	4
Another issue, addressed by P5, P6 and P7, is the latency when switching between the FX loops which should be shorter (and not noticeable).	3
The Scout should be more easily attachable to the headstock according to P7 and P9.	2
P4 and P5 state that the weight of the Scout does not bother them.	2
P3 notes the quiet click when switching.	1
P6 feels that the Scout was positioned too closely to the first fret and suggests moving it up the headstock.	1
The fret threshold of the left-hand setup should only be the trigger for the solo and, once above the threshold, the guitar player should be able to solo all over the fretboard until she or he plays more than one string (a chord) or performs a certain gesture signaling the left-hand setup to switch back to the rhythm sound (Suggestion by P1).	1
Another suggestion is to increase the flexibility of the fret threshold by making it adjustable via an expression pedal. Additionally, the Mothership should come with a bigger, color display that changes color according to activated FX loop (Suggestion by P1).	1
Another addition to the left-hand setup could be that it differentiates not only between frets but also strings (Suggestion by P5).	1

Another idea mentioned is that the left-hand setup could not only switch completely between FX loop 1 and 2 but also provide the possibility to blend between FX loops as well (Suggestion by P8).	1
Furthermore, the aesthetics of the left-hand setup were commented on, stating that it should be less obvious or visible. This is extremely important in some genres such as punk (Suggestion by P4).	1

C8: Technical integration right-hand setup

Statements	Total
P1, P2, P3, P5, P8 and P9 state that the right-hand setup works very well in conjuncture with the Wah-Wah effect and that it is a very reasonable option to control this effect.	6
P1, P2, P4 and P5 say that the right-hand setup is suitable for modulation effects which include tremolo, chorus and flanger.	4
P2, P5, P6 and P7 mention some of these effects such as delay or reverb for instance.	4
P1, P5 and P6 state that the right-hand setup is suited for practically all effects.	3
P3 and P9 deemed the delay amount to be inappropriate for the right-hand setup's control possibilities.	2
According to P5, the control possibilities are not restricted to effects pedals only but may be used to control all kinds of devices with a control input.	1
P8 notes that other filter-type effects such as the Moog MF-Drive can also be controlled well with the right-hand setup.	1
P4 believes that effects that show their potential while playing slower parts are said to be especially suitable for the right-hand setup.	1
P8 mentions that "ambiance" effects work well with the right-hand setup.	1
The shimmer-delay setting on the Boss DD-8 delay pedal controlled by the right-hand setup was particularly well received by P7.	1
According to P6, volume modulation could work well with the right-hand setup.	1
According to P4, a booster could work well with the right-hand setup.	1
According to P6, the amount of distortion could work well with the right-hand setup.	1

P5 states that the right-hand setup works well in experimental settings, for example when controlling a pitch shifter and/or feedback modulation.	1
P3 deemed reverb to be inappropriate for the right-hand setup's control possibilities.	1
P1 deemed the delay time to be inappropriate for the right-hand setup's control possibilities.	1
P3 deemed overdrive to be inappropriate for the right-hand setup's control possibilities.	1

The following effects are cited to work well with the right-hand setup:

Effects working with the right-hand setup	Mentioned by Participant #
Filter-type effects such as Wah-Wah	P1, P2, P3, P5, P8, P9
Reverb	P2, P5, P6, P7, P8
Delay	P2, P5, P6, P7, P8
Modulation effects such as tremolo, chorus and flanger	P1, P2, P4, P5
All effects	P1, P5, P6
Distortion	P6
Volume modulation	P6
Booster	P4
Pitch Shifter	P5
Feedback modulation	P5

C9: Musical integration right-hand setup

Statements	Total
P1, P2, P3, P4, P5, P6 and P7 describe the control possibilities of the right-hand setup to be simpler, more free, natural and delicate as well as more expressive in comparison to those offered by an expression pedal.	7
P1, P4, P7 and P8 are of the opinion that the right-hand setup is suitable for niche applications and should be used for specific situations like an effect.	4

According to P4, P5, and P7, the right-hand setup promotes creativity, widens the creative horizon, and opens new possibilities.	3
P1, P5 and P7 are of the opinion that the hand movements necessary go beyond those one is accustomed to and hence, proper handling must also be learnt.	3
P7, P8 and P9 state they find it easier to play in time with an expression pedal and say that they still prefer expression pedals for some features also because their hands remain free to play the guitar exclusively.	3
According to P1 and P5, the right-hand setup works well in ambient pieces because then, the playing style is adapted to play longer, sustained notes or chords which can then be modulated by the right-hand movements.	2
P6 and P7 specifically mention that it is fun to use the right-hand setup, which they deem a very important feature.	2
P7 and P9 state that the right-hand setup cannot entirely replace an expression pedal. Otherwise, conventional playing styles would have to be significantly altered, which some guitarists are not prepared to do.	2
According to P7 and P8, the processed accelerometer setting would have made more sense if the mapping had been flipped, at least in conjuncture with delay.	2
P5 explicitly states that the right-hand setup could be a substitute for an expression pedal.	1
According to P2, the control of the Wah-Wah effect via the right-hand setup is described as easier because by using the right-hand setup, guitar players are automatically in time.	1
According to P3, the control of the Wah-Wah effect via the right-hand setup is described as easier because by using the right-hand setup, guitar players are not forced to concentrate on being on time, thereby relieving them from cognitive load while playing.	1
P3 states that when using the Wah-Wah effect, the right-hand setup completely integrates into conventional playing techniques.	1
P5 describes the right-hand setup/Wah-Wah combination as being the better Auto-Wah. Sometimes the tempo of a song is too fast and Wah-Wah control by foot is no longer possible. Here, guitar players tend to use an Auto-Wah. The right-hand setup/Wah-Wah combination however is said to be better because it can be played in high tempo songs (because the hand moves sufficiently fast) AND it simultaneously provides more control possibilities than an Auto-Wah.	1
P4 notes that by using the right-hand setup, he can wear heavy boots without worrying about having no feel in the foot.	1

P4 notes that it encourages the use of effects because effects control is facilitated.	1
P6 says that the right-hand setup stimulates new (songwriting) ideas.	1
P5 states that the right-hand setup enables effects to dynamically adapt to the aspects of the current playing style (for example the tempo), resulting in less need to change settings manually.	1
P6 states that the right-hand setup adjusts itself and the effects to the groove of the song and hence, expressivity is promoted.	1
P5 notes that the right-hand setup makes effects control more visible and comprehensible for an audience. The right-hand setup may encourage guitar players to move in a more expressive way on stage.	1
P1 talks about love at first sight after using the right-hand setup for the first time.	1
P6 states that, apart from the live application, he primarily thinks the right-hand setup to be a fine tool within the studio environment.	1
P5 notes that many guitarists are already very used to controlling the Wah-Wah via foot movements and may therefore be reluctant to learn a new method.	1
P9 states that he perceives the right-hand setup as a limitation because it essentially takes away one control parameter, namely the foot.	1
P4 notes that the right-hand setup is not very suitable for punk music and here only suited for experimental song passages.	1
P3 states that the right-hand setup works great in funk music but not jazz.	1
P7, coming from classical guitar, notes that for fingerstyle techniques, the right-hand setup is not suitable as the hand is not moved enough to make effects control possible.	1
P7 states that the gyroscope setting has very useful applications.	1
According to P3, no significant difference was found between gyroscope and raw accelerometer data while using the Wah-Wah effect.	1
According to P7, the applicability of the processed accelerometer data depends on the setup used.	1

C9: General integration right-hand setup

Statements	Total

Seven participants (P1, P2, P4, P5, P6, P7 and P8) state that they would be able to integrate the right-hand setup and would use it during a live performance.	7
Disadvantage of the right-hand setup: Hand strap attachment of the Expressor perceived as annoying (P3, P9)	2
Two participants (P3 and P9) state that they would neither integrate the right-hand setup nor use it during a live performance.	2
Advantage of the right-hand setup: Possible substitute to an expression pedal (P2)	1
Advantage of the right-hand setup: Enables more natural control of the Wah-Wah effect (P3)	1
Advantage of the right-hand setup: Ensures that guitarists are always in time when playing the Wah-Wah effect (P2)	1
Advantage of the right-hand setup: Enables more independence and freedom of movement on stage (P2)	1
Advantage of the right-hand setup: Relieves guitarists of cognitive load (P4)	1
Advantage of the right-hand setup: Access to new modulation possibilities (P5)	1
Advantage of the right-hand setup: Enables more expressivity and musicality in effects control (P6)	1
Advantage of the right-hand setup: Visible effects control for audience (P5)	1
Advantage of the right-hand setup: Integrability in conventional playing styles possible (P5)	1
Advantage of the right-hand setup: Integrability in commercial setups (P5)	1
Advantage of the right-hand setup: Easy installation (easier than left-hand setup) (P5)	1
Disadvantage of the right-hand setup: Putting on the Expressor is time-consuming (P4)	1
Disadvantage of the right-hand setup: Aesthetics of right-hand setup (P4)	1
Disadvantage of the right-hand setup: Right hand setup is too visible (P4)	1
Disadvantage of the right-hand setup: Right hand setup restricts palm-muting technique (P4)	1

According to P7, an advantage that can simultaneously be a disadvantage is that the playing style must be adapted to the right-hand setup.	1
P6 adds that he would use the right-hand setup in the studio as well.	1

C10: Potential improvement right-hand setup

Statements	Total
P1, P2 P3, P5 say that the right-hand setup, in particular the Expressor, should be smaller and lighter to the point where it is not noticeable anymore.	4
P7 and P8 suggest that the Expressor should be easier to put on with references being a glove or a ring.	2
P1 suggests the dimensions of an EBow as reference.	1
P3 notes that particularly the strap running over the back of the hand should be thinner, so palm-muting is not impaired.	1
According to P1, the Expressor should not have a slider or pressure button to power it on or off. Otherwise, guitarists may easily turn it on or off by accident as they move their hand while playing.	1
P4 states that the right-hand setup is too visible, especially for genres like punk or black metal.	1
P5 was not bothered by the size and visibility of the Expressor. He states that small things are often not seen by the audience rendering effects control non-transparent.	1
The range of hand movement should be adaptable or calibratable in order to better fit the individual needs of each guitarist (Suggestion by P8).	1