Triplexer: An Expression Pedal with New Degrees of Freedom

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ABSTRACT

We introduce the *Triplexer*, a novel foot controller that gives the performer 3 degrees of freedom over the control of various effects parameters. With the *Triplexer*, we aim to expand the performer's control space by augmenting the capabilities of the common expression pedal that is found in most effects rigs. Using industrial-grade weight-detection sensors and widely-adopted communication protocols, the *Triplexer* offers a flexible platform that can be integrated into various performance setups and situations. In this paper, we detail the design of the *Triplexer* by describing its hardware, embedded signal processing, and mapping software implementations. We also offer the results of a user study, which we conducted to evaluate the usability of our controller.

Author Keywords

Expression pedal; foot controller; 3 degrees of freedom; hardware; interface

CCS Concepts

•Human-centered computing → User interface design; Sound-based input / output; •Applied computing → *Sound and music computing;*

1. INTRODUCTION

The expression pedal is a staple of many guitar effects setups. It allows the performer to map a continuous one-dimensional control to various parameters on other pedals (e.g. delay time, reverb amount). Additionally, wah wah and volume pedals, which directly alter the audio signal, rely on the same interaction design.

Given that the transfer of human weight through the foot can be applied with different intensities and in multiple dimensions, foot control can be used with finer precision to drive more than one parameter at a time. Although 3 degrees-of-freedom interfaces have been gaining more traction over the last decade, most of these new interfaces are geared for hand control, often in the form of augmented piano keyboards. With the *Triplexer*, we aim to offer a similar 3 degrees-of-freedom interaction in the form factor of an expression pedal. To enable the performer to use the whole weight of their body as a means of musical expression, we use extremely sensitive load cells and a series of signal processing techniques to derive 3-dimensional pressure data. Using the flexible output options on the *Triplexer*, this data can then be mapped to parameters in an effects setup or software to manipulate various qualities of sound.

In this paper, we offer detailed descriptions of the *Triplexer* hardware and software. We then describe various use cases both in terms of the device's integration into existing effects setups, and also in terms of how the users can interact with it. Finally, we offer the results of a user study, which we conducted with 10 musicians that have different degrees of experience with expression pedals. We analyze these results to determine the usability of our interface, and how it can be improved to better suit the needs of performers.

2. RELATED WORK

There are numerous hardware interfaces which offer multi-dimensional control. Many of these are designed for use with hands. For example, Wessel et al. describe interfaces composed of an array of 16 or 24 force-sensitive XYZ pads [11]. More recently, Roli has introduced the Seaboard[1], which expands upon the common piano interface with soft keys that are capable of tracking finger movements in three dimensions. Similarly, the Linnstrument[2] features a large array of pressure sensitive keys that also measure XY position.

In addition to such hand-oriented interfaces, there are also controllers that aim to improve the common foot switch and expression pedal design. A popular example is Keith McMillen Instruments' SoftStep 2[3], which is a multi-pad foot controller, where each pad is sensitive to changes in pressure and XY position relying on the manufacturer's multi-touch controller design [6]. The controller has 10 pads that are in the shape of a plus sign that is slightly smaller than 2 inches in width. While this layout offers a significant number of control outputs that can be mapped to various parameters, the size of the pads limits the area onto which the foot can be placed.

The Telonics FP-100[4] is based on the common expression pedal with the addition of sensors to determine the angular position of the pedal. This way the user can choose between various taper characteristics for the volume curve to achieve finer control over the pedal's attenuation of input signals.

The Pressure-Sensing Pedal [2] uses a force sensitive resistor (FSR) sandwiched between a piece of plywood and foam cut to the size of a foot. The pedal is designed for tracking taps for tempo adjustment. *Rhythm'n'Shoes*, by Papetti et

[1]https://roli.com/seaboard
[2]http://rogerlinndesign.com/linnstrument.html
[3]https://keithmcmillen.com/products/softstep/
[4]http://telonics.com/products/proaudio/fp-100.php

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al. is a wearable system that involves sandals that are similarly equipped with FSRs. The output of these resistors are used to control physical modeling synthesis [8]. Actuators on the sandals provide tactile feedback to the performer while wireless transmitters are used for untethered connection to a host computer. Each force sensor is sensitive to an upper limit of about 5 pounds, which is a typical drawback for FSRs under conditions that require a wider range of responses to weight. Like the Pressure-Sensing Pedal, *Rhythm'n'Shoes* is optimized for tracking transient events.

In another wearable design, Konvalovs et al. describe an apparatus that involve multiple motion sensors that can be attached to a shoe [4]. The apparatus detects specific foot gestures, which are used to switch effects on or off. While tilting the foot forward and backward can be used to control a wah wah effect, the primary use of the device is described as binary controls rather than those that are continuous. Based on a similar design, a patent filing from 2013 describes the use of various sensors in a shoe to track the movements of the performers foot [1]. The data gathered from these sensors are transferred wirelessly to a base unit, which maps these to various effects parameters.

Although several pressure and position sensitive foot controllers offer physical interfaces similar to that of the *Triplexer*, these differ in intended application and style of use. Some of these are geared towards tracking dance movements [10, 3, 9], and so they offer surfaces that are considerably larger than that of the *Triplexer*. The *footPad* [5] is a platform that is operated with both feet, and measures position, as well as tracking specific gestures. Its intended purpose is described as manipulating transport controls in digital audio workstations.

Figure 1 – The *Triplexer* with a semi-transparent image of a foot overlaid for illustration.

3. TRIPLEXER

To improve upon the single dimensionality of the common expression pedal, we designed the *Triplexer*, which is a foot controller that offers 3 degrees of freedom. Using industrial-grade load cells placed on each corner of the pedal platform, the device is capable of sensing fine movements on front-back (Y), left-right (X), and up-down (Z) axes. What sets apart the *Triplexer* from current offerings in multi-dimensional foot control is its sensing mechanism that is designed to measure heavy loads. This implies that the performer can use the whole weight of their body as a source of expression for detailed control of various effects parameters as demonstrated in our video abstract. [5] In addition to foot gestures used with expression pedals, the user can also utilize leaning and swaying motions, which can naturally occur during a performance, for parameter control.

The output of the *Triplexer* can be used to control other pedals or software: the embedded system supports two-way MIDI and Open Sound Control (OSC) [13] messaging as seen in Fig. 3. Since most modern DSP-based stompboxes implement MIDI communication, the *Triplexer* can easily be integrated into existing effects setups. A built-in screen on the controller, as seen in Fig. 1 facilitates the mapping of MIDI messages without requiring a computer. Furthermore, a desktop application, seen in Fig. 6 allows the *Triplexer* to communicate with any software via USB.

3.1 Hardware Design

The *Triplexer* hardware consists of a custom 3D-printed and laser-cut enclosure, a Teensy microcontroller, custom circuitry for processing sensor signals, a physical user interface, MIDI input and output, and a power supply. A layout of this hardware is seen in Fig. 2.

3.1.1 Electronics

To achieve 3 degrees of freedom with high pressure sensitivity, we used 4 button-style load cells located in each corner of the enclosure. Load cells, which are widely used for weight measurement in various commercial and industrial applications, are capable of measuring much larger forces than an individual force sensitive resistor. The load cells used in the *Triplexer* are rated for 200kg each, so it can respond to a very large range of forces without a risk of overloading the sensors.

Load cells work by forming a Wheatstone bridge with resistances that vary with strain on the sensor [7]. Because the resistances in the Wheatstone bridge change on the order of milliohms, the differential signal coming from the load cell is at a very low level. An instrumentation amplifier is used to get this signal from the millivolt range into a range usable by the Teensy microcontroller's analog-to-digital converter (ADC).

The on-board user interface consists of a character LCD screen and several buttons, which allow the user to perform calibration and navigate a menu system for the configuration of various settings including control mappings, optional inversion of each axis, response curves and pedal sensitivity, and saving and loading settings from the bank in EEPROM.

The MIDI circuitry was designed to comply with the MIDI electrical standard. It supports IN, THROUGH, and OUT connections, which makes the *Triplexer* easy to use in various MIDI setups with keyboards, effects pedals, and other musical interfaces. Panel mount MIDI jacks are positioned on the front edge of the electronics enclosure.

Power is supplied using a 2.1mm barrel jack, which is common for effects pedals. This way, the *Triplexer* can be integrated into existing pedal power systems, such as the

[5] `https://vimeo.com/triplexer/video`

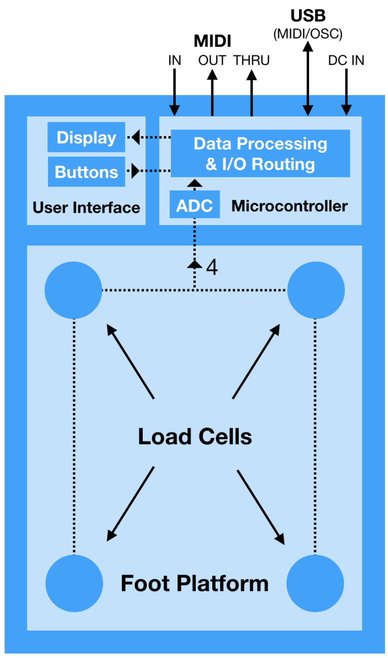

Figure 2 – *Triplexer* hardware layout.

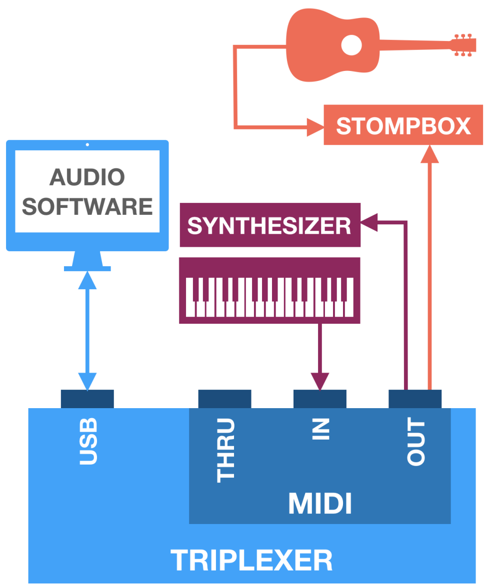

Figure 3 – *Triplexer* input/output ports and some of their possible use cases.

Voodoo Labs power supplies[6]. Voltage is regulated down to 5V for MIDI circuitry, per the MIDI standard, and 3.3V for the rest of the design. The entire circuit is custom-fitted onto a 2-layer PCB.

3.1.2 Enclosure

The *Triplexer* has been designed with portability in mind. The enclosure, seen in Fig. 1, consists of two main sections, both attached to a base plate that forms the footprint of the device. The platform, custom built from a sheet of quarter inch 6061 aluminum, is 12" by 6", with a layer of rubber padding on top. The height of the platform is 1", which makes it much shallower than the common expression pedal. The platform rests on four load cells positioned near its corners. These load cells are attached with machine screws to the base plate, which is also 6061 aluminum. This material was chosen to achieve a high level of durability under user weight.

The electronics and on-board user interface are housed in a 3D-printed box fixed on the bottom plate where the foot surface ends. MIDI, USB type B, and DC power jacks are all located on the far end of this box away from the user's foot. The screen and the buttons are on the top surface of the box.

3.2 Software Design

3.2.1 Data Transmission and Processing

The *Triplexer*'s embedded software implements a series of signal processing and data processing techniques, which transform the raw data from the load cells into useful OSC and MIDI messages. The overall latency from sensor input to the completion of USB data transmission is approximately 3 ms, which is under the with the 10 ms latency requirement suggested by Wessel and Wright [12]. The signal flow of this process is seen in Fig. 5. First, input values from each load cell are adjusted for individual zero-balance and sensitivity. These calibrated values are then used to calculate a center of mass value, which is used to derive raw X and Y positions. The data from individual cells are also summed for the Z value, which reflects the total weight. The total weight can be adjusted for each user via a calibration process, which sets the maximum desired total weight. The calibration process can be initiated at any time using the physical UI of the controller.

The calibrated and averaged X, Y, and Z values are used as indices into response curves for each axis. The user can adjust these curves for each axis using two parameters, each ranging from 0 to 100 with a step size of 1. The first is a "sensitivity" parameter which controls the shape of the response. A value of 0 produces an exponential shape, a value of 50 produces a linear shape, and a value of 100 produces a logarithmic shape. The second curve parameter is "width", which allows the perceived dimensions of the platform to be adjusted in software to fit a user's foot size and style of use. Specifically, it adjusts the range in which indices result in outputs between zero (for low raw input values) and a maximum value (for high raw input values). Indices outside this range all produce the maximum or minimum output value. A value of 0 results in a curve which uses about half of the available length along an axis, and a value of 100 uses all of the available length. Fig. 4 shows the range of possible response curve shapes.

The processed signals are output as MIDI and OSC messages. Since they are calculated as 16-bit integers, the least significant 9 bits are discarded for MIDI output. The MIDI

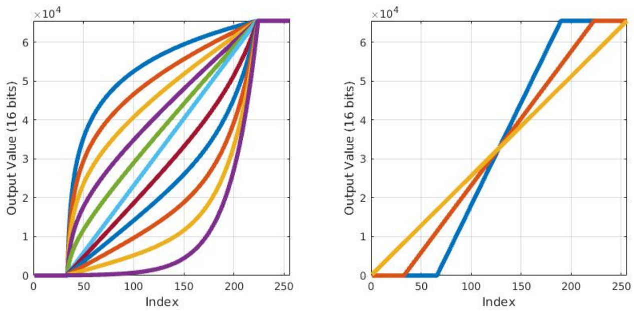

Figure 4 – Left: Response curves, ranging from exponential through linear to logarithmic shape; right: response area widths (blue: 0, red: 50, yellow: 100)

[6]http://www.voodoolab.com/pedalpower_landing.html

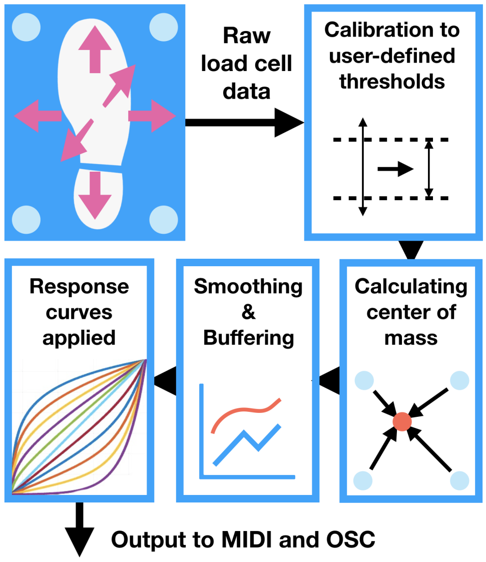

Figure 5 – *Triplexer* signal flow from user interaction to MIDI/OSC output.

and OSC messages are also output at the *Triplexer*'s full 1 kHz over USB, but MIDI using the much slower conventional UART port is downsampled to avoid starving out other MIDI signals.

If no force is applied to the platform, instead of going through the process described above, outputs are calculated from the most recent non-zero values. This allows the user to remove their foot and have the system maintain its state, which is similar to leaving an expression pedal at a particular angle. A separate ring buffer keeps a history of values for this purpose. The user can achieve the effect of zero total weight applied (i.e. a Z value of 0) by leaving the foot in light contact with the platform for a brief moment before removing it.

3.2.2 *Front-end User Interface*

The OSC capabilities of the *Triplexer* facilitates the external control of various device settings, as well as the mapping of the sensory data to software parameters. The performer can use any software that supports OSC to configure the device in real-time. To further facilitate this process, we designed a software using PureData, as seen in Fig. 6, that serves as both a device configuration tool, and a mapping interface for routing messages between the *Triplexer* and other software.

3.3 Applications

In general, the *Triplexer*'s potential uses extend to any domain where the 3D-parameter space or hands-free operation are of use. Its primary intended use is as an interface to control external effects. In this use case, the user's hands may be occupied with playing an instrument while the feet are used to expressively control effects parameters. The output ports on the device facilitate connection to other effects pedals or to a computer, while GUI available on the device or on a connected computer make it easy to configure and route as desired. We have tested several specific use cases. For example, a guitarist controlling pedals with MIDI inputs, or a keyboardist controlling synthesizer parameters by inserting the *Triplexer* between a standard MIDI controller and a synthesizer. Because USB MIDI and OSC are available, it is also simple to control effects in computer software.

The *Triplexer* can also be used as a stand-alone instrument. We have experimented with using it to control sound

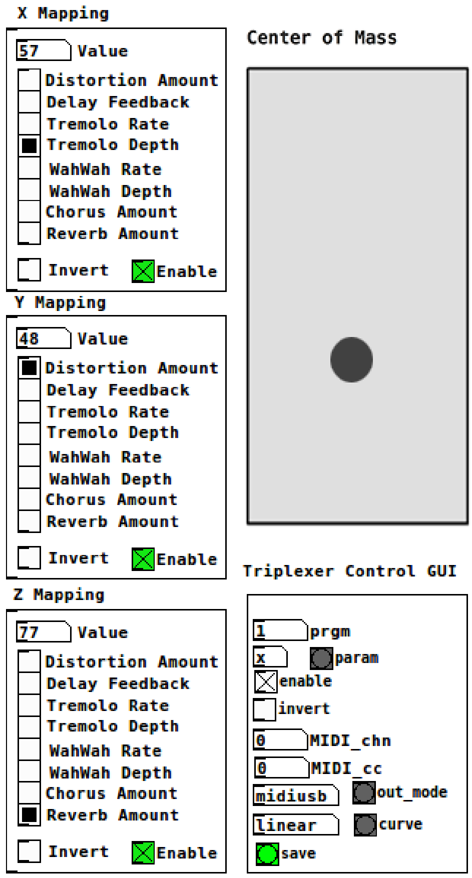

Figure 6 – User interface of the *Triplexer* mapping software built in PureData.

generation in PureData by mapping its output to the amplitude envelope, quantized pitch and filtering of a synthesized sound. We found the one-millisecond time resolution to be sufficient to provide a sense of smooth expression in this context, and the 3-dimensional foot control of sound generation felt intuitive.

In a similar application, we mapped the outputs of the *Triplexer* to various parameters of a granular synthesizer. We found the use of the whole weight of the body to control, for instance, the density of grains in a continuous cloud to create interesting gestural metaphors.

3.3.1 *Extended Techniques*

The platform can be used physically in a variety of ways. Perhaps the most obvious way is by placing a single foot on the platform, and leaving it there for continuous control. This mode of interaction is the most similar to how existing expression pedals are used.

Another approach is to place both feet on the platform. This can be done while facing to the side, a method of use we refer to as "skateboard" style. We found the pedal's 3D output in relation to the user's swaying motions in this pose to yield intuitive results when mapped to effects. The pose also makes it especially easy to reach anywhere within the continuous range of the left-right and front-back axes. The resulting gesture is similar to those performed on a Wii Balance Board, which also performs a center of mass calculation to facilitate fitness applications within the Wii framework. [7]

If ongoing control is not desired, the *Triplexer* can be

[7] `http://wiifit.com/`

used more as a switch. When it detects that no weight is applied to the platform, it stays in the same state as before weight was removed. As a result, the platform can be used as if it were a stompbox switch by stepping briefly on the platform to achieve some combination of settings, and then removing the foot from its surface.

4. USER STUDY

We conducted a user study to evaluate 1) the usability of the *Triplexer* as a 3-degrees-of-freedom expression pedal, 2) mapping strategies between effects parameters and the *Triplexer*'s control axes, and 3) extended techniques for the *Triplexer* in various performance contexts. Every instance of the study was recorded audio-visually. We worked with a diverse group of musicians to assess various scenarios in which the device can be used to augment an existing setup, or facilitate novel use cases.

4.1 Participants

The study was conducted with 10 participants. Among the participants were 8 guitar players who had varying degrees of experience with effects pedals ranging from not having used them at all to having professionally performed with pedals for several decades. Among the two remaining participants were a professional pianist and a violinist. The pianist had some experience with expression pedals, while the violinist had no experience using effects of any kind. Each study lasted approximately 45 minutes.

4.2 Method

The participants were first given a brief tutorial on the operation of the *Triplexer*. The following study consisted of three sections.

In the first section, the participants were presented with a set of pre-determined mappings between effects parameters and control axes. These were ”distortion amount” on the front-back (Y) axis, ”tremolo depth” in the left-right (X) axis, and ”reverb amount” on the up-down (Z) axis. The choice of parameters in this section was made with the aim of having individual axes address separate (i.e. spectral, temporal, and spatial) qualities of sound that can be easily distinguished from one another. The users were first introduced with the axes in isolation so as to allow them to gain a sense of the pedal's response in individual axes. They were then asked to try two-axis combinations (i.e. X-Y, X-Z, and Y-Z). Finally, they were asked to perform with all three axes enabled. At the end of the first section, they were asked to fill out a brief survey.

In the second section, the users were introduced to the *Triplexer*'s desktop software, which allows the mapping of axes to parameters as seen in Fig. 6. They were then asked to try out different combinations of parameters on each axis, and perform with these settings. The available parameters in this section included ”distortion amount”, ”delay feedback”, ”tremolo rate”, ”tremolo depth”, ”wah wah rate”, ”wah wah depth”, ”chorus amount”, and ”reverb amount”. At the end of this section, the users were asked to fill out another brief survey.

In the third section of the study, the users were asked to explore extended techniques for using the *Triplexer*. Among these were some of the techniques we discussed under Section 3.3, such as mounting the pedal sideways with both feet using the ”skateboard” style, depressing the pedal non-uniformly (i.e. by partially mounting it), and tapping parts of the pedal of the surface. The users were also encouraged to try out any techniques that they could think of. The users were then asked to fill out a final survey.

4.3 Results and Discussion

In the first section of the study, we were primarily interested in monitoring the users' general interaction with the *Triplexer*, to what extent they were able to control the individual axes, and how this affected their performance. In Fig. 7, it can be seen that the users rated the up-down axis the most comfortable to use, with left-right described as the least comfortable. When asked about which combination of two axes felt most natural, 6 of the 10 users responded ”up-down and front-back”, 3 users said ”front-back and left-right”, and 1 user said ”up-down and left-right”.

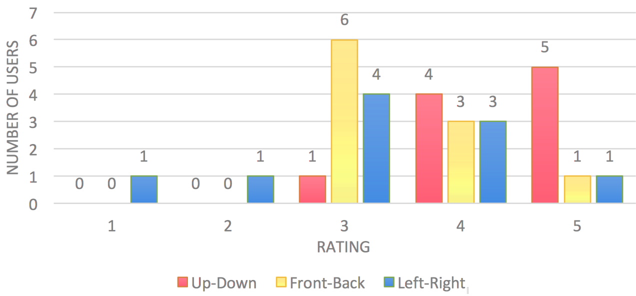

Figure 7 – Responses to questions about how comfortable it was to control a parameter using an individual axis (i.e. either up-down, front-back, or left-right), with 0: not comfortable at all, 5: very comfortable.

In the second section, we were interested observing which effects combinations they deemed to be most suitable for controlling within the 3D parameter space. Most users spent about 15 minutes experimenting with various mappings. In the following survey, the users were asked to identify the effects that were best suited for the individual axes during 3D control. With the number of users indicated in parentheses, for the front-back axis the users listed tremolo (4), wah wah (3), distortion (1); for the up-down axis: reverb (2), wah wah (2), delay (1), tremolo (1), chorus (1), distortion (1); and for the left-right axis: tremolo (3), wah wah (2), distortion (1). Although there is no significant trend in these responses, tremolo and wah wah effects were the most frequent answers across all axes. Also interestingly, reverb and delay effects were almost exclusively listed for the up-down axis. Although our sample size is fairly small, this result encourages further research into whether the embodied interaction involved in controlling the up-down axis with the user's full weight has a kinesthetic relationship with the senses of prolongation and spatial expansion involved in reverb and delay effects.

One user primarily focused on controlling effect rates on different axes (e.g. tremolo rate on one and wah rate on the other) to create cross-effect beatings. A violinist, who did not have previous experience with effects pedals, said she was surprised by how natural the translation of her movements into effect changes was. When the users were asked about what other effects would be suitable to be controlled with the *Triplexer* but were not included in the study, the responses included volume, phaser, and filter.

In the third section, we aimed to understand whether any of the extended techniques we outlined in Section 3.3, were considered by the users as viable methods of performing with the *Triplexer*. We were also curious to see what other methods the users would come up with. The ”skateboard” technique was overwhelmingly popular among the participants. Users described that they were able to transfer the natural sway of their body during a performance to the control of a parameter, which felt more natural than explicitly controlling a pedal.

In the survey that followed this section, in addition to expressing their thoughts on the extended techniques, the users were also asked to provide general comments and requests regarding the *Triplexer* in the form of linear-scale ratings and written responses. In response to a question about how the Triplexer could be integrated into the user's existing setup or playing style, 3 users mentioned that it would best be used to augment their existing setups. 3 users deemed suitable for more experimental uses such as continuous shaping of tone and texture. One user stated that it would be best for controlling time and space based effects, while another mentioned that they would use it with effect that would widen the sound of their acoustic guitar.

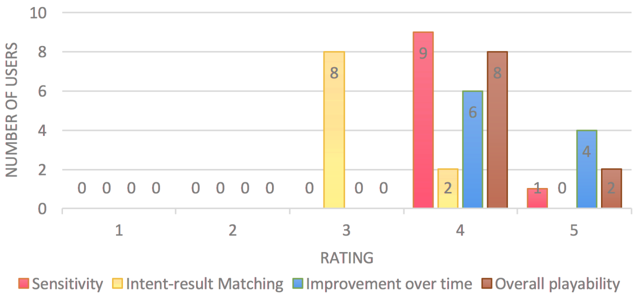

Figure 8 – Responses to questions asking users to rate 1) the sensitivity at which the *Triplexer* responded to user movements (0: not sensitive at all, 5: very sensitive); 2) how the user's intents while performing with the *Triplexer* matched the results (0: did not match at all, 5: matched perfectly); 3) whether the user's control over the *Triplexer* improved over time (0: strongly disagree, 5: strongly agree); and 4) how playable the *Triplexer* was overall (0: not playable at all, 5: very playable).

One user who had professional experience working with people with disabilities argued that the *Triplexer* would potentially be more accessible than a conventional expression pedal for that population. Shifting weight on a platform could hypothetically be done in a variety of ways that would require less dexterity while, for instance, seated on a platform.

5. FUTURE WORK AND CONCLUSIONS

Based on the promising results of our user study, we have outlined several possible improvements for the *Triplexer*. The PureData tool that visualizes the user's position on the pedal, seen in Fig.6, was initially designed as a debugging tool during software development. During our preliminary studies, it became apparent that some visual feedback is useful while using the *Triplexer*. This assumption was further confirmed during the second part of the user study, where participants were allowed to use the visual monitor while choosing parameter mappings. All participants found the display helpful, and several suggested that a similar display would be useful on the device itself. Accordingly, we elaborated a new design of the *Triplexer* that includes a graphical display instead of a character display, so that, in addition to the menu system being available when needed, it would also be possible to display the foot position on the pedal.

The general preference among users towards controlling time and space based effects has prompted us to conduct further research into the kinesthetic relationship between audio affects and their embodied cognition. As a result of this, we hope to identify audio effects combinations that can be built into the *Triplexer* so that it will also function as a stand-alone effects pedal.

The strong preference towards the "skateboard" technique has encouraged us to explore different mechanical designs including a longer platform which the users could more easily mount with both feet standing sideways. We also intend to create calibration presets for different poses, such as playing while sitting down. These presets will automatically set the response curve in a way that better suits the use case.

We believe that the *Triplexer* improves upon the common expression pedal design in a way that significantly expands the performer's control space. It facilitates the integration of the user's bodily expressions into performance practices with a form factor and connectivity options that fit within existing effects setups.

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