AxeTron

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ABSTRACT

The AxeTron is an electric guitar designed with portability and live performance at the forefront, with a focus on novel control surfaces and tone capabilities. It is an all-in-one package that gives guitarists access to their entire arsenal, without requiring them to carry around all of their gear. Each effect can be controlled individually with knobs, buttons, and touchpads on the guitar itself. Additionally, players can switch between different presets, which can be customized by the player. The AxeTron also supports advanced functions, such as looping and a drum machine, and contains a built-in theremin for even more tone variety. Users who are experienced with programming can also upload their own firmware to the AxeTron for absolute control over its functionality.

1. INTRODUCTION

The primary motives for developing the AxeTron were to decrease the footprint of a gigging musician, while still providing them with a diverse set of effects and tools. Musicians often need to haul around a lot of equipment, sometimes enough to warrant using a vehicle. Minimizing the load on a musician while preserving their toolkit is the goal of this project. The key to doing so is taking a digital effects processing unit with a small enough size, and seamlessly embedding it into the instrument itself.

2. BACKGROUND

2.1 Integrated Guitar Systems

Integrated effects in guitars was an idea explored in the late 1960s, but was dismissed as a gimmicky fad. However, with the modern introduction of MIDI, instrument designers have been exploring this idea once again. In particular, electric guitars with integrated MIDI support have been surfacing on the market, offering novel tone control methods and compatibility with virtual instruments and digital pedals.

2.1.1 Roland GS-500

The Roland GS-500[2] was one of the earliest examples of what was possible in the realm of integrated guitar effects. The design featured a control module that was mounted on the guitar, which would connect to an external GR-500 synthesizer. The knobs duplicated the controls on the actual synthesizer, but the guitar also featured a three-way EQ toggle switch. The guitar only contained a single pickup, so the switch was intended to simulate the tonal possibilities of a guitar with multiple pickups.

One of the most unique features of this guitar was its 'Infinite Sustain.' Two powerful magnets of opposite polarity were placed outside the strings, which created a strong magnetic field across the strings. The frets on the guitar are grounded to the strings in order to prevent the introduction of noise into the signal. The guitar has a hexa-phonic pickup that detects the vibration of the string, amplifies the signal, and alters the magnetic field accordingly, thus allowing the string to vibrate at that frequency 'infinitely'.

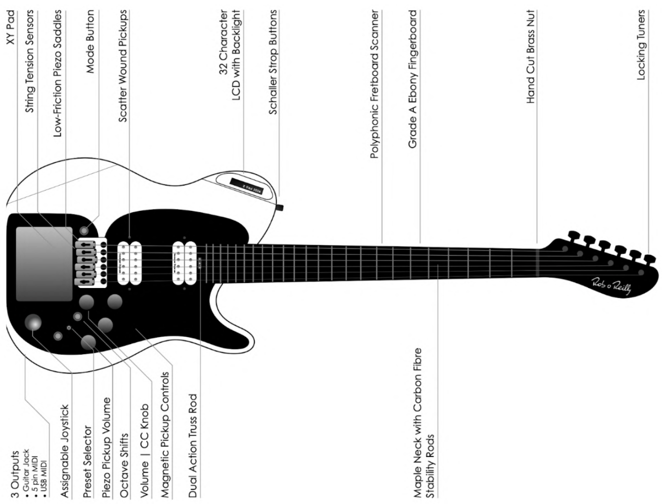
2.1.2 Godwin Guitorgan

The Godwin Guitorgan[1] is a fascinating instrument that is both rare and unique in its design. It was created in the 1970s by Robert Godwin, who was inspired by the original Gibson Guitorgan[8] but sought to create an instrument that would offer an expanded range of organ sounds and greater control over those sounds.

The Godwin Guitorgan features six guitar strings and a bank of twelve organ keys, much like the Gibson Guitorgan. However, it also includes a variety of additional controls and features that make it a more versatile and expressive instrument. For example, it has an expanded set of organ voices that can be selected using a series of switches and buttons, allowing the player to create a wide range of tonal colors and textures. It also has a built-in Leslie speaker, which provides a distinctive rotary speaker effect that is commonly associated with the sound of classic Hammond organs.

Playing the Guitorgan requires a high degree of skill and coordination. The right hand is used to play the guitar strings, while the left hand is used to play the organ keys. The player's feet control various parameters, such as the volume and speed of the Leslie speaker, using a set of pedals. Despite its technical complexity, the Guitorgan has been embraced by many musicians as a versatile and innovative instrument. The general concept of merging another instrument with an electric guitar is in line with our project. More specifically, the control layout serves as an inspiration for how the embedded effects unit might be controlled by the player.

2.1.3 *Expressiv MIDI Pro 2*



The Expressiv MIDI Pro 2[6] is a highly-advanced MIDI guitar controller, designed by Rob O'Reilly. It can also be used as a regular analog guitar by bypassing the embedded digital electronics, if the user desires. What separates this guitar from a traditional electric guitar is the variety of unique control surfaces that have been incorporated into the body of the instrument.

The guitar features three switches, which control preset selection, octave transposition, and semitone transposition. Additionally, it features a double-axis joystick that can be used for pitch bending, or programmed for alternative effects. Lastly, it features a double-axis touch pad that can be used for triggering notes, changing velocity ranges, pitch bending, and various other MIDI effects.

The double-axis touchpad is a standout feature that will be incorporated into the design of the AxeTron. Typically, this type of control surface would be found on a synthesizer, but would be a valuable tool for a guitarist as well. For example, a user could map one axis to reverb, and the other to a low-pass filter, in order to achieve a spacious tone. However, this is just one example, and the possible pairings of effects are endless.

The Expressiv MIDI Pro 2 also contains an onboard microprocessor, which runs at 16MHz and has an onboard memory capacity of 4KB. This allows the user to program up to 30 presets on the guitar, which are displayed on the LCD screen near the strap button. Compared to other audio-centric microprocessors, these specifications are quite low, but still deliver great performance, which demonstrates the advantages of relying on the MIDI protocol.

2.2 Standalone Effects Units

Effect pedals for guitars have been around since the 1940s, but relied on analog components. The digital audio revolution allowed multiple effects to be combined in much smaller designs, while still honoring their analog counterparts. Products like the Quad Cortex[4] and the Line 6 Helix[3] are at the top of the market, offering expansive libraries of effects and utilities to guitarists. These products are also updated constantly with ever-growing community presets, some of which aim to emulate analog gear. This flexibility is extremely advantageous, and offers the opportunity for players to achieve desirable tones without spending exorbitant amounts of money on vintage analog gear. This type of modularity guided the design of the AxeTron, which can be programmed at the firmware level for precise needs.

3. PROJECT DESCRIPTION

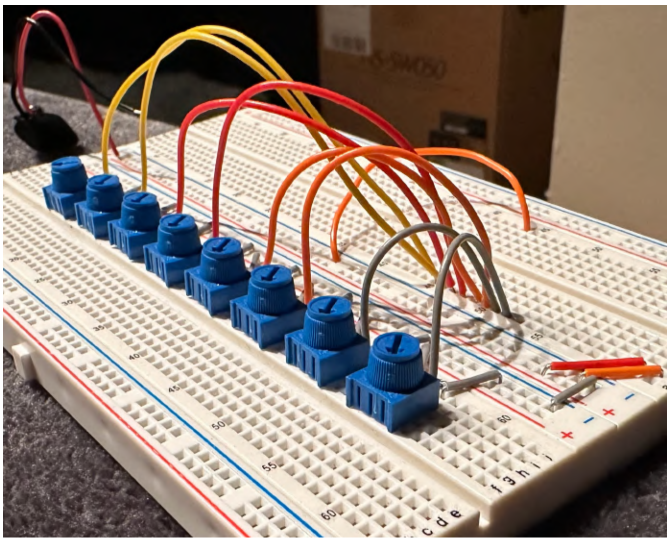
3.1 Software Development

The first stage of the design process was exploring the potential of the Daisy Seed [5]. The Daisy Seed is a powerful microcontroller development board designed for audio and music applications. It is an open-source hardware platform based on the STM32 microcontroller and features an audio codec, MIDI interface, and a range of digital and analog inputs/outputs. With its compact size and versatile functionality, the Daisy Seed is ideal for musicians, hobbyists, and developers who want to create their own digital audio effects, synthesizers, and other music-related projects. The Daisy Seed is also fully compatible with a range of software development tools, making it easy to program and customize. The Daisy Seed was chosen for this project, since its specifications were in line with what we wanted to accomplish.

In terms of writing software for the Daisy, the Arduino development environment was chosen for simplicity. We experimented with C++ and Pure Data, but C++ became too complex and Pure Data lacked certain features that we desired. The Arduino development environment was also preferred due to the vast support resources surrounding it, including the DaisyDuino [7] library.

```
void AudioCallback(float **in, float **out, size_t size) {
  for (size_t i = 0; i < size; i++) {
    float input_sample = in[0][i] * 8;
    float output_sample = input_sample;
    if (knob1 > 0.01) {
      output_sample = fuzz(output_sample, knob1);
    }
    if (knob2 > 0.01) {
      flanger.SetLfoDepth(knob2);
      output_sample = flanger.Process(output_sample);
    }
    if (knob3 > 0.01) {
      phaser.SetLfoDepth(knob3);
      output_sample = phaser.Process(output_sample);
    }
    if (knob4 > 0.01) {
      compressor.SetThreshold(knob4 * -80.0);
      output_sample = compressor.Process(output_sample);
    }
    if (knob5 > 0.01) {
      tremolo.SetDepth(knob5);
      output_sample = tremolo.Process(output_sample);
    }
    if (knob6 > 0.01) {
      autowah.SetDryWet(knob6 * 100);
      output_sample = autowah.Process(output_sample);
    }
```

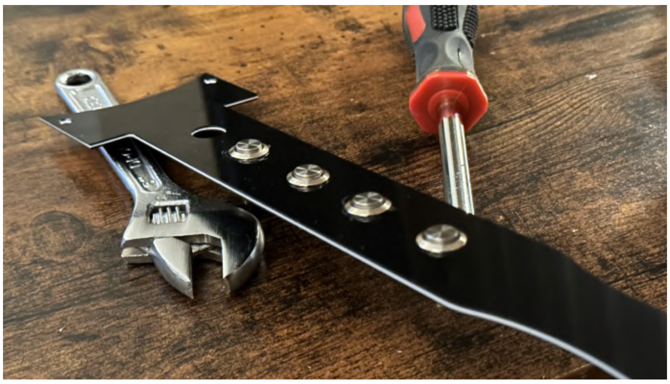
The development process began by implementing desired effects, such as distortion, tremolo, auto-wah, and flanging, in the Arduino environment. A breadboard fitted with trimmers and a speaker in order to test each effect. We began by assessing each individual effect and then testing all of them running concurrently. The Daisy was able to handle the computational load of ten effects running in tandem, which was promising. Additionally, we observed no latency in the audio during testing, which confirmed that the Daisy would be able to handle live performance.



After testing the functionality of knobs as control surfaces, we moved on to testing buttons and the double-axis touchpad. These yielded similar results, which confirmed that they could be used in our final design.

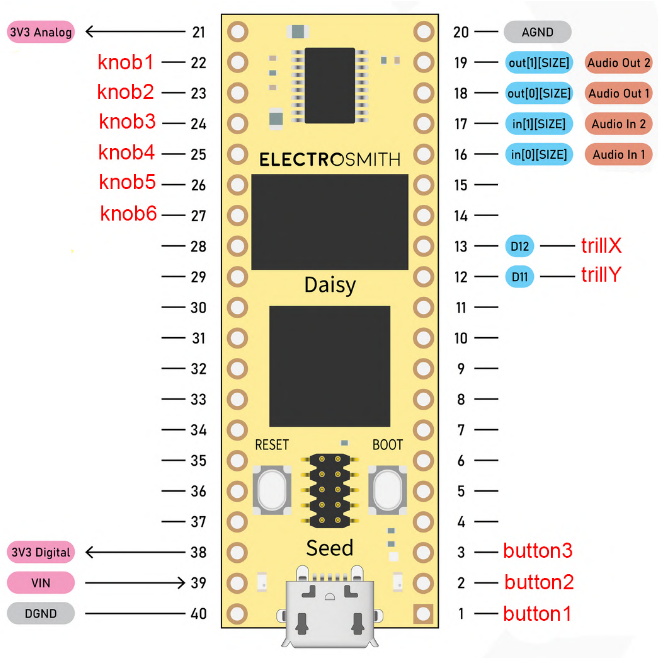
3.2 Fabrication

There were several adjustments that needed to be made to the body of the guitar in order to fit all of the hardware. We drilled six holes in the body to accommodate the potentiometers, which would be used for controlling the level of each effect, or for individual effect parameters. Additionally, we drilled three holes in the center pickguard in order to accommodate the buttons, which would be mapped to the looper, drum machine, and preset selector.

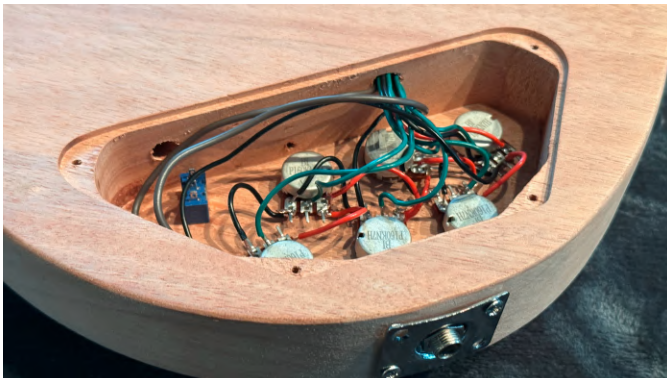


We also drilled a hole for the Trill board (double-axis touchpad) in the front of the guitar to feed cables through to the back of the body. Lastly, we routed out a section in the back of the guitar body in order to accommodate the Daisy and the battery, which were mounted on a protoboard.

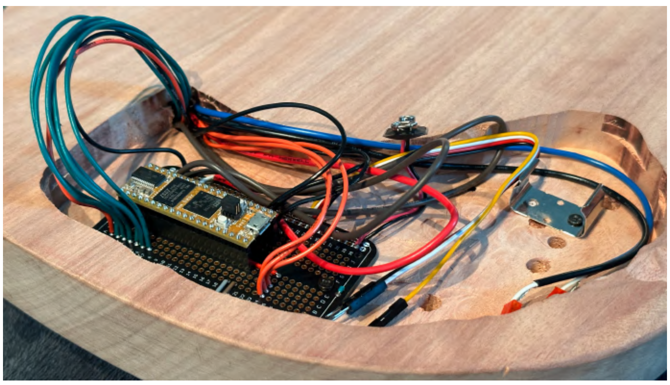
3.3 Electronics



As seen in the above diagram, each of the control surfaces on the guitar was routed into the appropriate pins on the Daisy. The wires for each were routed through existing holes in the body (used for pickups and switches). The audio output of the Daisy is in stereo, so a stereo TRS jack was installed in the guitar, which is atypical.



The six potentiometers were daisy-chained together in order to reduce the number of wires running through the body. Additionally, copper wires were used throughout the circuit, with heavily-insulated cables used for wires carrying audio signals, in an attempt to reduce noise entering the system.



3.4 Playability

The onboard effects were designed to stay within moderate ranges in mind to ensure consistent control of tone and to limit the chance of hard clipping. The guitar is relatively light for a double-neck guitar which allows for longer sessions without shoulder pain from a strap. Accessing the preset buttons is efficient because of their location between the two sets of pickups. The XY pad is reasonably comfortable to operate, however, because of its position on the body you may be forced to short-arm it. Switching the position of this pad around is something we would consider doing over time if we find that it slows down the performance capabilities.

4. CHALLENGES

During the construction of this project, there were several challenges we faced. One of which was the amount of room for electronics to be connected within the guitar. There is a significantly larger amount of wire in this build when comparing it to a standard guitar. While the double neck is certainly an exciting aspect of the instrument, it brought on more difficulties than anticipated. Another obstacle that we faced was a lack of equipment access due to schedule conflicts. As a result, weren't able to utilize a CNC router and had to make the cuts with a hand-held router. This made the cutting process less accurate and put us behind schedule.

5. CONCLUSIONS AND FUTURE WORK

AxeTron is an extremely capable performance tool that ultimately accomplishes what we set out to do. It reduces the amount of gear needed to perform and also adds another variable to increase playability.

Overall, future improvements for this design are limitless. Due to the flexibility of the Daisy, and being able to easily upload custom firmware, many features could be added. For example, in order to make the guitar more user-friendly, a USB jack could be added which would allow the user to record directly to their computer. Additionally, a separate headphone jack could be added for practice purposes. The Daisy also contains a multitude of sensors that could be used for controlling certain effects. For example, the accelerometers could be used to control the distortion level, so that tilting the guitar upwards would increase the distortion. Furthermore, the Daisy has Bluetooth and Wi-Fi capabilities, which would allow users to play backing tracks from their phones. This would also open the possibilities for users to link the AxeTron to their phone, in order to control all of the effects, or browse presets uploaded by other users.

Moving forward, we will use the knowledge we gained during the development of the AxeTron for future projects involving music hardware. Assembling a guitar is no easy task, which became evident as we moved through the development process. Additionally, since the Daisy Seed is relatively new, there is limited support and documentation for it, which allowed us to explore its capabilities to great depth, at the expense of time spent learning how to use it effectively.

6. ACKNOWLEDGMENTS

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7. REFERENCES

[1] Godwin guitorgan. `https://www.synthmuseum.com/godwin/godguit01.html`, 1974.

[2] Roland gs-500. `https://www.roland.com/global/products/gs-500/`, 1995.

[3] Line 6 helix. `https://line6.com/helix/`, 2015.

[4] Neural dsp quad cortex. `https://neuraldsp.com/products/quad-cortex/`, 2021.

[5] Daisy seed electro-smith. `https://www.electro-smith.com/daisy/`, 2022.

[6] Expressiv midi pro 2. `https://expressiv.com/products/expressiv-midi-pro-2`, 2022.

[7] Daisyduino library. `https://github.com/electro-smith/DaisyDuino/`, 2023.

[8] Gibson. *Gibson Guitorgan Manual.* Gibson Inc., 1967.