Motion-Based Control For Guitar Effects Processing

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Abstract
We describe the design of a system in which the motion of an electric guitar is used to control effects applied to the instrument's audio output.

Keywords
Guitar, effects processing, motion

ACM Classification Keywords
H.5.5 Sound and Music Computing.

Introduction
Contemporary electric guitarists often employ audio processing effects to vary the audio output of their instrument. These effects manipulate the audio signal coming from the guitar by clipping it, adding delay, or introducing other time-varying changes to the signal. The character and variety of effects varies widely across musical subgenres, and while some guitarists may employ a few specific effects, many (such as most rock and prog-rock guitarists) employ a diverse battery of effects to achieve an astonishingly wide array of sounds.

Effects are commonly modulated using effects pedals; small boxes placed in-line between the guitar and amplifier that contain audio processing circuits. Often a performer will chain a long series of pedals (**figure 1**) each with a different circuit. Alternately, many modern guitarists use more sophisticated pedals that allow digital sound processing and can emulate and combine multiple effects, removing the need for a large number of individual pedals. However, the limited affordances of a foot switch mean performers typically have simple on/off controls for specific effects or can linearly vary only one effect or variable at any given time.

Our system seeks to untether guitarists from the physical limitations of foot pedals by allowing them to control audio effects processing using the motion of the guitar itself. We mount wireless accelerometers and orientation sensors on the guitar's neck and then use the three-dimensional movement and orientation of guitar to move between one effect and another and to control specific variables of individual effects. This permits guitarists to range more freely about the stage in a performance setting. More importantly, by leveraging the motion range of the arms and upper body rather than just the feet, our system enables guitarists to more fluidly and organically vary and combine effects.

Related Work

A substantial amount of prior work has focused on music generation using various inputs. Hunt et al's work on selecting appropriate mappings between inputs and outputs for sound synthesis [4] is relevant to our work, although our inputs control audio processing rather than synthesis.

Several guitar-simulation systems – the computer-vision based Air Guitar Simulator [5] and the textile motion sensing Wearable Instrument Shirt [2] – have

figure 1. Board containing a set of chained guitar effects pedals. (www.hamage.com/guitar.php)

explored the simulation of guitar-like audio based on body motions which mimic those made when playing a physical guitar.

Other work has focused, as ours does, on using gestural input not for sound generation, but to control effects processing for already generated sounds. These include the E-mic system [3], which uses physical motion from a microphone stand to control audio processing of vocal tracks. Bell et al's Multimodal Music Stand [1] uses computer vision to track the motion of performers' heads and instruments and uses that input to modify their audio output.

A commercial product that uses motion input to control guitar effects processing has also been recently released by Source Audio LLC.[7] Their product, known as the *Hot Hand*, includes an accelerometer that guitarists can wear on their hand (or potentially their head, or foot) and which is used to modulate *wah* and *flanger/phaser* effects.

figure 2. Guitarists utilize a range of playing positions.

Motion & Guitar Technique

Guitarists exhibit a variety of different playing and performance styles that may vary dramatically across performers and across musical subgenres. The performance style of many rock, punk, and hardcore guitarists, for example, is characterized by energetic body motion and movement about the stage, punctuated by jumps, thrusts and guitar gestures (see **figure 2**) A jazz or blues guitarist, on the other hand, may perform while seated and exhibit a much less frantic or exaggerated range of motion.

Interestingly, these gestures and motions are often more about stage presence and the impact of the performance rather than producing a specific sound from the instrument. In fact, because the audio produced from the guitar depends only on the vibration of and tension the strings, only the position and motion of the hands is typically relevant. Generally, a soloing lead guitarist who raises his or her guitar to the characteristic near-vertical position (seen in **figure 2**-right) could produce the same sound in a neutral position. This gesture, then, is actually a way of emphasizing the act.

Because guitarists already make these sorts of gestures and often coordinate them with the music, common mappings between pose and style of play frequently occur (even across individuals). Thus, using these inputs as a control for effects processing is not unnatural. A few common effects/gesture pairings (distorting a raised guitar or shifting its pitch to simulate the whammy bar accessory used by many rock soloists or transitioning a lowered base guitar to a throbbing, fuzzy distortion) are nice illustrations of this. Moreover, pairing the effect and the motion allows substantially greater control of the effect.

The flip-side of this pairing is that using motion as a control requires the guitarist to constantly be conscious of the relationship between position and sound and orchestrate their physical performance accordingly. Doing so limits the guitarist’s ability to move freely, since every major motion of the upper body corresponds to a change in audio.

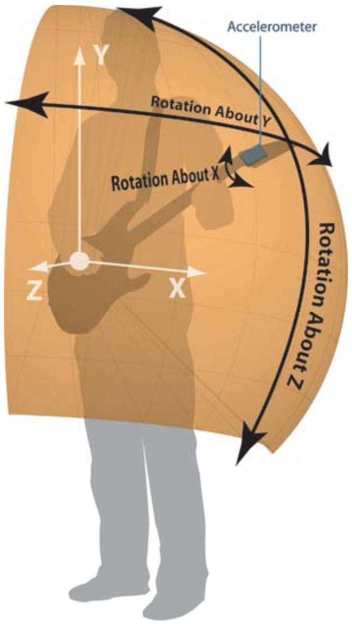

figure 3. Guitar motion relative to the body.

Ergonomics of Guitar
The form factor and position of the guitar relative to the body, as well as the requirement that both hands remain at the appropriate places on the instrument limit the range and types of motion available as inputs. The weight of the guitar also makes the instrument difficult to support with the arms, so guitarists generally either carry the instrument using a strap which runs over the shoulder and around the back, or rest the instrument on their upper leg, further limiting range of motion.

We can consider the orientation of the guitar in three dimensions, its translation in 3D space or the acceleration in any of these dimensions as possible inputs. Translation is problematic because it requires physically sliding the guitar in a given direction, either by moving the entire body or by lifting, pushing, or pulling the instrument. Rotating the instrument, however, is much easier since in a natural playing position the guitar pivots against the body at its base. Moreover, this orientation can be varied smoothly by positioning the shoulder, elbow, and wrist of the opposite arm. This allows a guitarist rotate the instrument up and down as well as towards and away from the body as seen in **figure 3**.

In general, we can imagine rotating the guitar with respect to three axes (see **figure 3**). For the purpose of discussion we'll imagine these axes as centered at the pivot point at the guitar's base(a simplification since that pivot can actually move) where the X axis points left and right, the Y axis points up perpendicular to the ground plane and the Z axis points forward away from the guitarist. We'll refer to up/down motion in a plane perpendicular to the ground plane as rotation about Z, towards/away motion in the plane parallel to the ground as rotation about Y, and pivoting of the guitar about a line running from the body up the instrument's neck as rotation about X.

The guitar's attachment to the musician's body and the necessity of placing both hands comfortably on the instrument to depress strings along the length of the fretboard while strumming and picking restricts rotation in all of these directions. Based on our observations,

An Few Potential Effects

Volume – The overall decibel level of the signal.

Distortion/Fuzz – The hallmark of most rock guitar. The signal is distorted by amplifying the audio signal and then clipping the peaks of the waveforms. Many variations exist and number of independent variables including the amount of compression and tone can be adjusted to vary the strength and character of the distortion.

Delay/Echo/Chorus – Echoing the audio signal after a variable time interval. Can produce a fuller or more textured sound (depending on the amount of delay).

Pitch Shifter – Moving the actual tone or frequency of the signal up or down. Often achieved on electric guitars by pulling a "*Whammy Bar*" which varies string tension.

Auto-Wah – One of numerous more complicated effects. Produces the distinctive sound characteristic of most 1970s funk and disco. The entire effect or a number of variables can be tweaked.

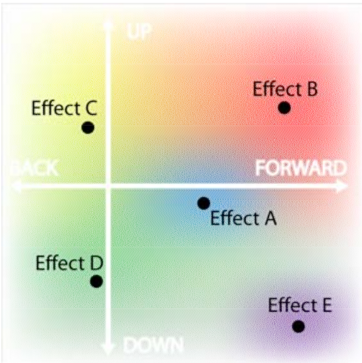

figure 4. Effects at 2D positions.

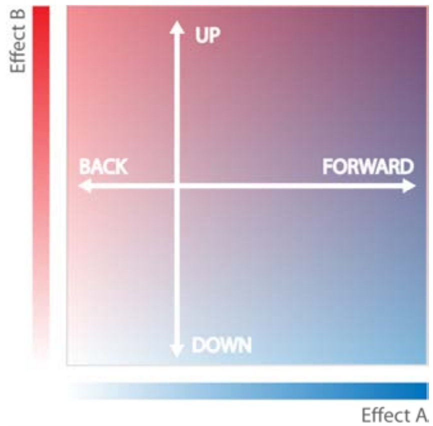

figure 5. Effects along axes.

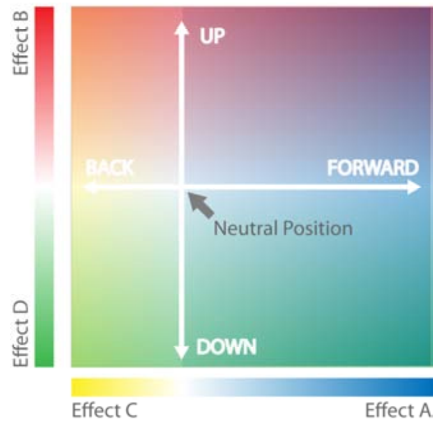

figure 6. Two-per-axis effects.

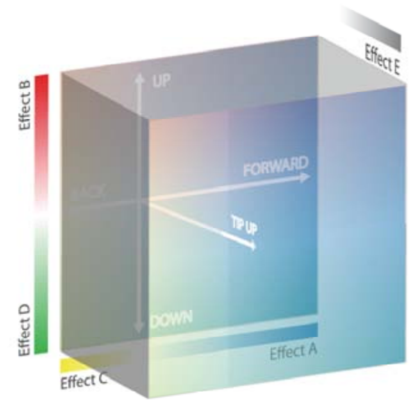

figure 7. Two-per-axis with tilt.

most guitarists can maintain control of the instrument while pivoting up to about 85° from horizontal and down to about 45° below horizontal. They can pivot the guitar away from their body to about 85° past the plane of the shoulders and rotate the neck back towards the body to about 15° behind that plane. Rotation about X is substantially more difficult. Guitarists may be able to rotate the instrument to about 45° from vertical (or even further in a few dramatic moves) by arching their back and pivoting the base of the guitar out but these positions are very difficult to maintain, let alone play in.

Guitarists can comfortably maintain a much smaller range of orientations in each of these directions over long periods of play. This range centers around a neutral position where the neck of the guitar is rotated about 30° up from horizontal and not rotated at all about the other two axes.

Mapping Space to Effects

A musician can rotate the guitar about the Y and Z-axes simultaneously, allowing them to fluidly navigate a 2D space of possible effects. Several possible methods exist for mapping the motion in this space to changes in audio effects.

One technique is to map individual pre-configured effects such as a Fuzz Distortion or Auto-Wah to specific locations in this 2D space. The performer can then select and cross fade between effects by orienting guitar towards their positions in the space. (**figure 4**) However navigating this mapping requires that the guitarist memorize the locations of the effects in the space (particularly difficult when the only feedback provided is the audio output) and individual variables for a given effect cannot be easily varied.

Another approach is to map effects along axes of the 2D space. (**figure 5**) The amount to which a complex effect like distortion is applied to an output can be varied along one axis of motion such that the effect is *off* at one extreme, *on* at the other and varies linearly across all of the positions between them. Adjustments to specific variables (like the amount of delay or the compression threshold of a more complex effect) can also be varied along one of the axes. This kind of mapping is problematic, however, because the most natural guitar positions are always in the middle of the space while the desired effects are at its extrema.

A more natural mapping (**figure 6**) breaks each axis in two and maps a separate effect or variable to motion in each direction. This means that the guitarist can specify one effect at the neutral position and one effect or variable along each direction of each axis. Here, as in the previous case, effects mapped orthogonally to one another can be combined to varying degrees by navigating the quadrant of the space in which they overlap. We use this mapping in our implementation.

It is also possible to map the input from the third rotational axis to yet another effect or variable orthogonal to these two axes, giving a 3D space of possible effects. However, the difficulty of rotating about X while strumming and/or rotating about one of the other two axes makes it a good candidate for only a few effects (such as sustain) that might be applied when not playing.

Feedback Loop
While using this system, a guitarist has several mechanisms for judging where their instrument is oriented within the space of potential effects. The most obvious of these is audio feedback. Because the position of the guitar has an immediate effect on the audio produced by the system, guitarists can use the audio itself to gauge position within the space. Since we use a mapping scheme in which the extremes of motion correspond to fully applied effects users have a clear sense of where to navigate from their current state in order to increase or decrease the an effect (provided they can distinguish that effect in the audio output).

While our prototype application also provides some visual feedback about the current position, we believe that a visual component should not be an integral part of the system. Forcing a guitarist in a performance environment to constantly monitor a visual display is problematic. Other tangible and ambient feedback may be more useful, however, and we discuss this prospect briefly in *future work.*

Implementation
We have constructed a functional prototype of the system that takes accelerometer input and supports a small number of effects.

Hardware
A wireless accelerometer attached to the headstock of the guitar behind the machine heads measures the orientation of the guitar in the up/down direction and provides motion information in three directions. This orientation and motion data is transmitted to a laptop for audio processing. Other inputs wired to an Arduino microcontroller area also sent to the same laptop.

The current implementation does not include sensors for determining absolute orientations in directions not orthogonal to the downward pull of gravity. However, future versions will also mount a sensor on the guitar to determine the total amount of in/out rotation or the distance between the guitar and the body. This sensor could be a digital compass with a manual reset to allow tracking of orientation regardless of the direction the musician is facing, or an infrared or ultrasonic distance

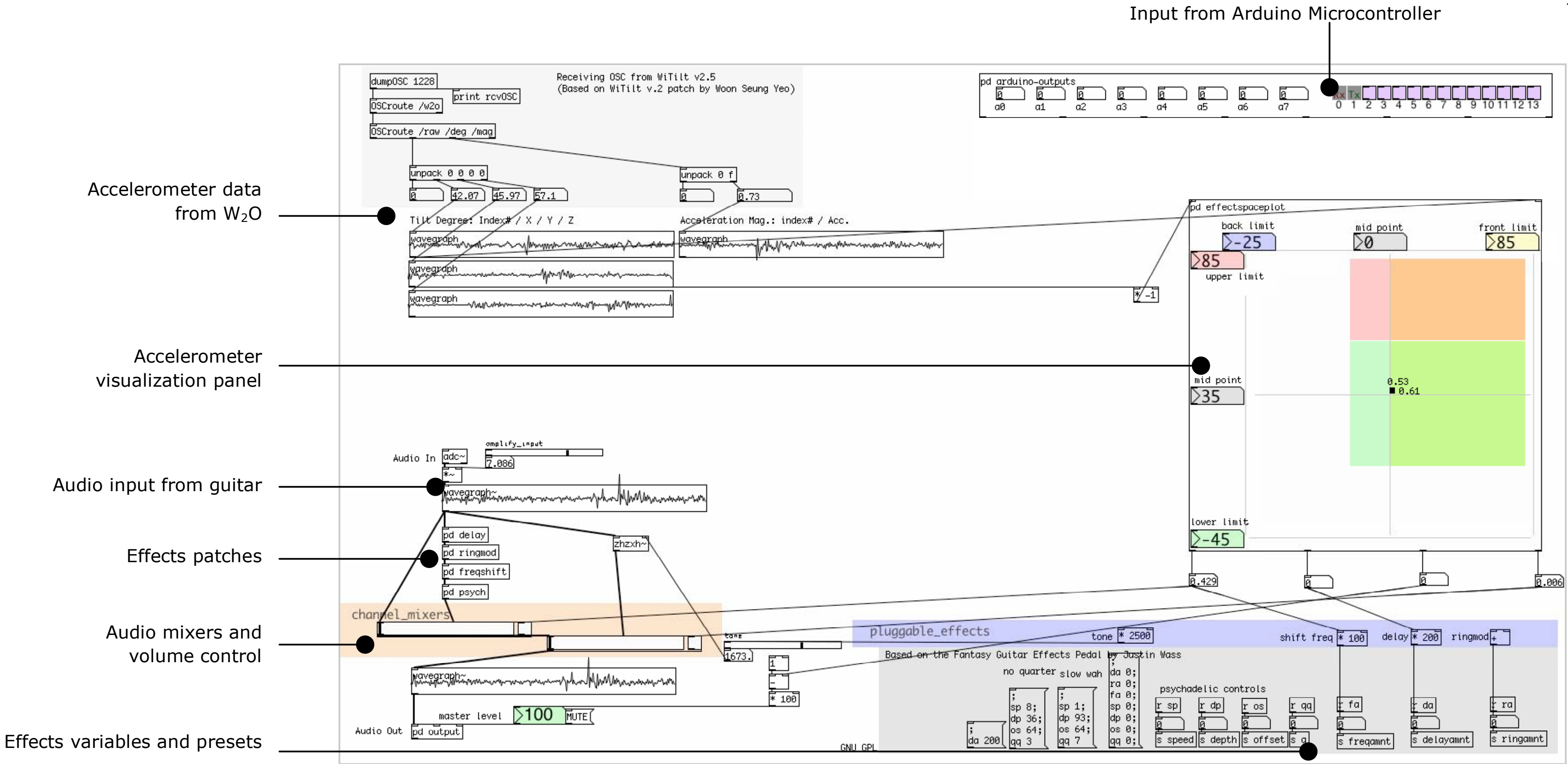

figure 8. A screenshot of the Pd application used to pair motion input with effects processing.

sensor designed to measure the distance between the guitar body and the guitarist's abdomen.

Software

The software required to handle accelerometer input and carry out audio processing has several components. We utilize Pure Data (Pd) [6]– an open source patch-based programming and audio processing environment similar to MAX/MSP – as the underlying platform in which to process the guitar audio. Accelerometer input is processed using a heavily modified version of Woon Seung Yeo's W_2O processing application [11], which translates input from the accelerometer into Open Sound Control (OSC) packets which can be read from within Pd. We also use Hans-Christoph Steiner's Pduino package [9] to provide Pd input from an Arduino microcontroller for debugging and to augment the accelerometer inputs.

Within our Pd application (seen in **figure 8**), audio input from the guitar is routed into a series of effects patches at the left hand side of the screen.

Accelerometer input can be monitored at the upper left hand corner, while Ardiuno inputs are shown at the upper right. Along the bottom of the screen are inputs that control which effects are applied to the incoming channel and to what degree. Controls for more specific variables in these effects – including reverb and pitch control as well as tone control for the distortion package – are also included. We use a suite of existing patches to provide most of the available effects including components from Julian Wass's Fantasy Guitar Effects Patch [10] and Ben Saylor's zhzxh [8].

We use several custom components in this Pd application to better facilitate the mapping of accelerometer inputs to sound outputs and accommodate the natural range of guitar motion. The accelerometer visualization patch (at the right side of **figure 8**) plots the current rotation of the guitar in the up/down direction (shown on the Y axis) and in/out direction (shown on the X axis) from -180° to 180°. A black marks the current position of the guitar while a colored block behind it indicates the portion of the total possible range of motion mapped to effects. This block is roughly equivalent to the 2D space of effects shown in **figure 6**. A white line drawn through the middle of the block in each orientation indicates the neutral angle of the guitar (in this case about 35° from horizontal in the up/down direction and at 0° in the in/out). The upper and lower limits of this colored block correspond to the most extreme angles that the guitarist can comfortably reach. Controls along the top and left of the patch are used to adjust these limits. Four outputs on the bottom of the patch provide normalized values between 0 and 1 based on how close the current guitar position is to the upper extreme, lower extreme, inner extreme, and outer extreme respectively. (Again, these correspond to the four effects mappings found in **figure 6.**) Each of these outputs can then be wired to one or more of the mixers and effects variables present at the bottom of the screen.

It's important to note that this configuration is designed to be variable and we don't intend this particular setup to be widely used. Rather, these patches can be recombined in any number of ways along with other audio processing code to achieve a an even greater range of customizable effects. Performers might even change the configuration dramatically over the course of a single performance.

To better illustrate, we'll describe the interaction produced by the Pd application shown in **figure 8**. Here, a neutral guitar position in both axes produces a clean, un-doctored sound. Rotating the guitar out produces an increasingly distorted sound via the zhzxh patch while rotating it in from the neutral point decreases the volume. Tilting downward increases the amount of delay applied to the audio signal, and tilting up applies a pitch-shifting effect, allowing quick up-and-down motions of the guitar to simulate the use of a whammy bar.

Future Work

While the current system is capable of a huge number of different combinations of effects, the configuration mechanism – adding and linking patches in Pd – is too weighty to really be useful outside of a studio setting where a keyboard and mouse are accessible. A more streamlined interface for pairing inputs with effects variables and for saving configurations and presets is probably necessary to support live performance. One can imagine, for example, a touch-screen interface in which a user simply taps an accelerometer input and effects variable in tandem to pair them. Alternately, such a system might present a bank of effects that could be dragged onto a visualization of the space of guitar motion in order to assign that effect to a position or axis within the space. We may also want to consider utilizing more complex mappings in which each input dynamically varies more than one variable in an effect, especially in light of Hunt et al's finding [4] that (in music synthesis applications) mappings which are not one-to-one can be more engaging that those that are.

Even this level of configuration and adjustment, however, is probably not appropriate for a live performance. In such a situation, a performer is unlikely to want to spend much time actually setting up effects, but will most likely still want to move amongst a number of preconfigured effects mappings. One option here is to return to using foot switches to control the transitions between preconfigured sets of effects, recognizing that transitions between set are likely to occur less frequently than the changes to individual effects that pedals normally support. Another, less explored option might be to use the acceleration values from the guitar to trigger transitions between sets of effects. For example, fast motions with the guitar neck – especially in the directions that do not interfere with the actual angle of the instrument and thus would not alter the other effects – might be used to "bump" the guitar from one configuration into another.

This raises the issue of feedback. The current system depends almost entirely on audio feedback to help the guitarist navigate the space of effects. While we do provide visual feedback within our Pd application, this is not well suited for use on stage, since it requires that the performer focus his or her attention on the display. Additional tactile or visual feedback on the guitar itself might be valuable – for example the instrument might glow increasingly in a representative color as the guitarist approached the extrema of the configured range, or the instrument might vibrate softly to confirm a state change.

Because of the flexibility of the system – data from the accelerometers and the calibrated output of our processing are just scalar numbers between 1 and 0 – it might also be possible to use the system to control aspects of the performance beyond just the audio processing. Coupling these outputs to stage lighting, or even using them to control an additional audio device like a drum sequencer, could be entirely viable.

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