Axis: Motion-Controlled Audio Effects: Real-Time Gesture Processing on Custom 3D-Printed Embedded Hardware

Tufts UNIVERSITY

Project Leads: Paul Wang ‘27, Seamas Ruiseal '27, Ryan Flood ‘27
Tufts University

Problem:

Traditional guitar effects pedals rely on static knobs and switches for parameter control, limiting real-time expression and forcing musicians to manually adjust settings mid-performance. While digital effects offer sophisticated processing capabilities, they typically lack intuitive, hands-free control interfaces that allow performers to dynamically modulate effect parameters without interrupting their playing.

Our Solution:

Our solution is a headstock-mounted system that uses guitar tilt to control effects in real time. Instead of stopping to adjust knobs or pedals, players can simply change the angle of their instrument to shape their sound. By pairing motion sensing with digital audio processing, we provide a more intuitive and hands-free way to modulate effects—allowing guitarists to stay focused on performing while still accessing dynamic tonal control.

Human-Centered Design Considerations:

Our design decisions are guided by how guitarists interact with their instruments in real performance settings.

Guitar Safety & Trust
· Protect the instrument’s finish and avoid tension on the headstock so players feel comfortable mounting the device.

Attachment Intuitiveness
· A simple, secure clamp mechanism that mounts quickly and stays out of the way during performance.

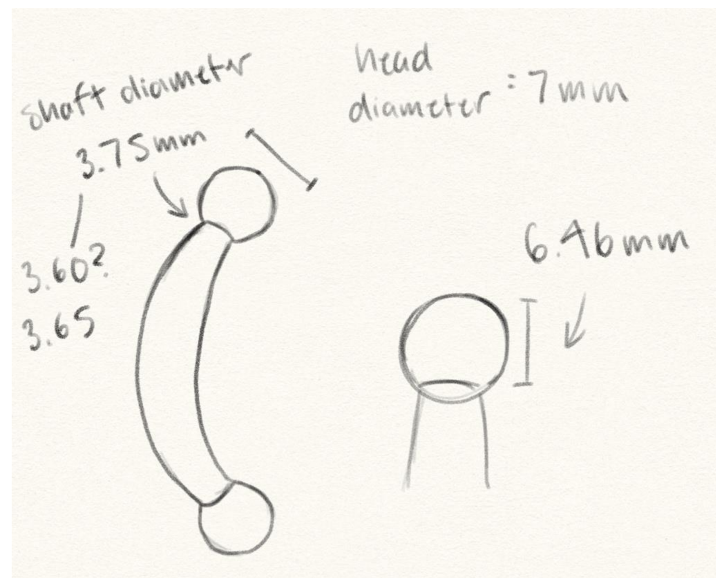
Form Factor & Comfort
· A lightweight, low-profile housing that doesn’t affect balance, technique, or access to tuning pegs.

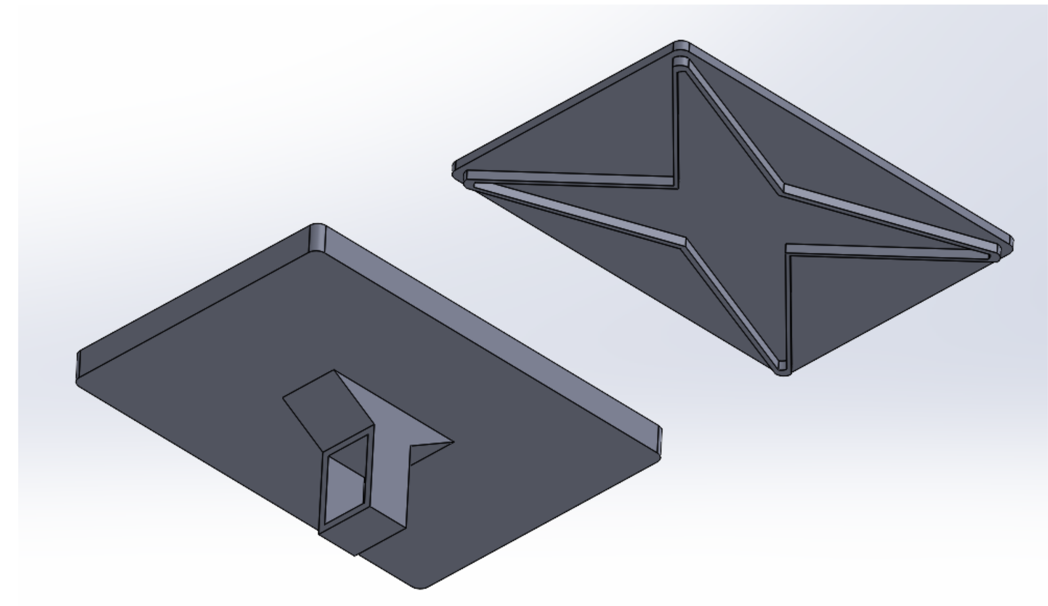
Clear Feedback & Controls
· A straightforward interface so users understand when the device is active and how it’s influencing effects.

Mechanical/HFE Team

The Mechanical/Human Factors team is designing the physical housing + mounting system that will hold the electronics securely on the guitar. We've explored multiple attachment concepts to balance stability, aesthetics, and instrument safety. Our focus is on creating a sleek, lightweight design that installs easily, protects the guitar’s finish, and supports intuitive tilt-based control, to enhance the musician’s experience without disrupting their playing.

Prototypes + CAD Models



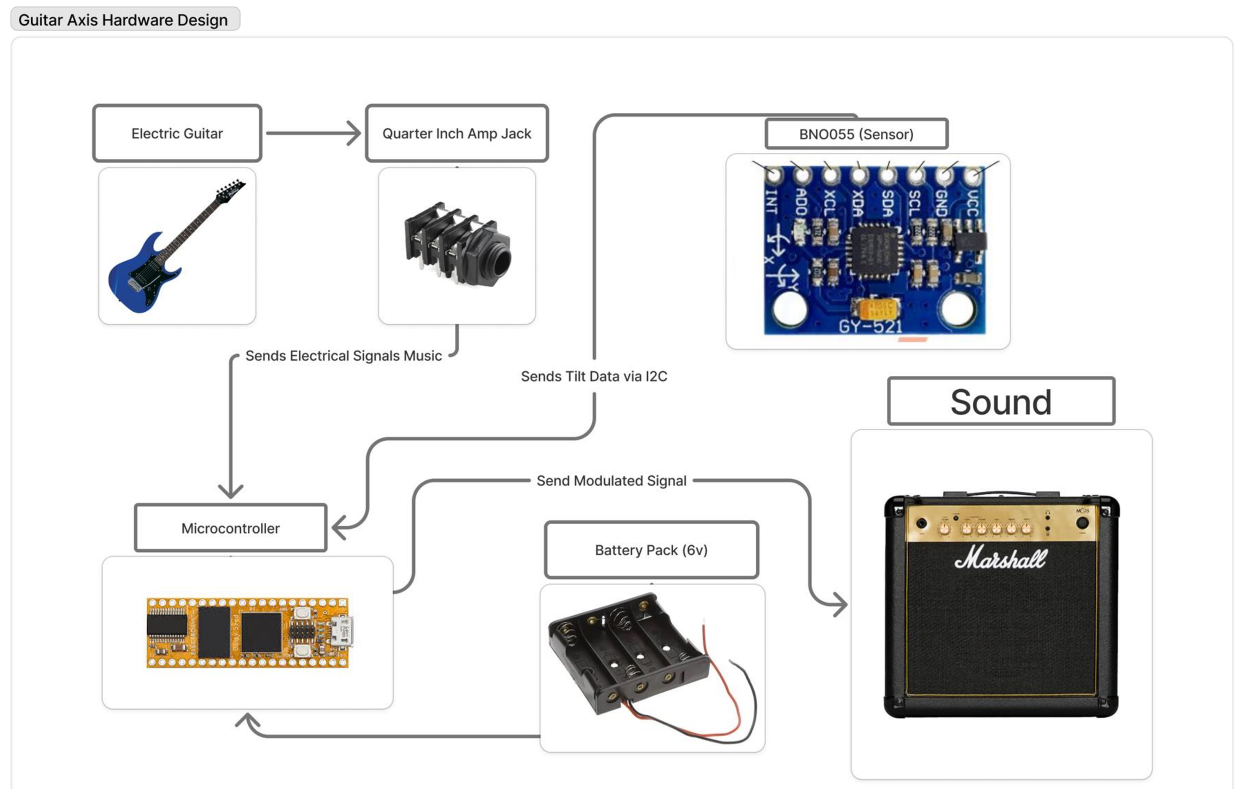


Our prototypes began primarily focused on testing different lid attachment mechanisms, with a stem fit for our simple clamp. These prototypes taught us about different locking mechanisms and allowed us to create a low-fidelity design which was efficient and able to be tested on. We then moved to integrate the Snark tuner, which is the most widely used tuning attachment among players at all levels. This tuner uses a ball-and-socket joint, so we were able to utilize the already established clamp to fit the next round of our designs.

Electrical Team

The Software team developed the embedded firmware and real-time audio processing system that bridges motion sensing with sound manipulation. We established I2C communication with the MPU6050 sensor, implemented a 48kHz audio pipeline with sub-10ms latency, and created motion-controlled effects including tremolo and dual flanger sequencing. Our focus was on architecting a thread-safe system that separates sensor polling from audio processing, ensuring glitch-free operation while maintaining professional audio quality and responsive gesture control that enhances musical expression without compromising performance.

Block Diagram



Our implementation uses the native libDaisy/DaisySP framework rather than Arduino-based wrappers, providing direct hardware control and optimized real-time performance. We manually configured the MPU6050 registers via I2C communication, including waking the sensor from default sleep mode (PWR_MGMT_1 register) and setting gyroscope/accelerometer sensitivity ranges for precise motion tracking.

Firmware Design

Motion data is mapped using a custom Map() function that converts sensor angles (roll/pitch) into musically useful parameter ranges—pitch controls tremolo depth (0-100%) while roll modulates frequency (2-12Hz). This dual-thread architecture ensures the audio callback never blocks on I2C reads, maintaining professional audio quality while achieving responsive gesture control. The small audio block size (4 samples) minimizes latency, critical for the immediate cause-and-effect relationship musicians need during performance.

Next Steps – Mechanical

Integrating Electrical Systems into Hardware
- With the final chip specifications, we will design the housing to secure and provide it power, allowing it to modulate the audio without impeding the player.

Water & Heatproofing + Safety Testing
- We will ensure the device is water and heat resistant by adding a heat sink and gasketed lid. Safety testing is paramount for us , as we're is positioned as an accessible tool for vulnerable communities.

User Testing & Community Feedback
- We will conduct field tests to gather user insights and work closely with performing guitarists and disabled players, ensuring our design serves our communities.

Further Iteration on Housing Design
- Feedback from our testing and user groups will directly inform our future iterations as we address the challenges that come with system integration.

Designing for Manufacturability
- We are researching manufacturers and working with professors in relevant fields to learn what it takes to bring a product to market.

Next Steps – Electrical

PCB Design
- Design a custom PCB to integrate all embedded components—Daisy Seed, MPU6050 IMU, audio codec, and power regulation—into a compact, manufacturable form factor optimized for pedalboard use.

Sensor Calibration
- Implement filtering algorithms (complementary or Kalman filters) to distinguish intentional gestures from unwanted noise and sensor drift, preventing false triggers during performance.

More Guitar Sound Effects
- Expand the effect library with chorus, phaser, reverb, and delay. Each effect will feature motion-mappable parameters across multiple axes for enhanced expressive control.

Integrated IOT WIFI Support
- Add WiFi connectivity to enable wireless operation and remote configuration. Users can adjust effect parameters, manage presets, and update firmware through a web interface or companion app without interrupting performance.