Electric Hero: a Guitar-based Music Learning Tool & Game

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Overview

Electric Hero is an interactive rhythm-based game that transforms real-time guitar input into an engaging gameplay experience. Using a Raspberry Pi 5 and custom-built software, the system captures audio signals from an electric guitar, checks the played notes using digital signal processing techniques, and visually maps them onto a six-lane interface that mirrors traditional guitar strings. By blending live musical performance with intuitive visual feedback, Electric Hero creates an accessible and entertaining platform for both musical practice and gaming.

Motivation

The idea for Electric Hero originated from our team's shared passion for both music and technology. Recognizing the widespread popularity of rhythm games like Guitar Hero, we wanted to create a system that bridges entertainment and real musical performance. We saw an opportunity to use embedded systems and digital signal processing to turn a real guitar into a playable, interactive experience. Our goal was to make music practice more engaging, accessible, and rewarding for a broader range of learners.

Hardware

The Electric Hero system is built around a Raspberry Pi 5, which serves as the main processing and visualization unit. An electric guitar is connected to a USB audio interface – specifically, the Focusrite Scarlett 2i2 – where the signal undergoes preamplification and capturing high-quality audio capture before being processed by the Pi 5. A monitor is connected to the Pi 5 to handle all the game visualization.

Note Matching Software

The core mechanic of this game requires us to match a user-input note with a note from a pre-recorded track. Accurately classifying a note and matching is a difficult task, especially with chords and harmonics. Also, even if the right frequencies (notes) are played, they may not employ the right guitar effects.

To get around both problems, we designed a more robust system that analyzes the input signal against the pre-recorded track without needing to classify them into notes. Given windows of an input signal and a pre-recorded track, we take the discrete Fourier transform to analyze the frequency components. Then, rather than extracting note information from the two signals we compare them directly. We first smooth out the frequency information by convolving with a Gaussian (in frequency domain). Then we run a peak selection function, only the most prominent frequencies of a signal are considered. This makes it easier to compare just the signal and not the noise. The resulting signal is a sparse vector with a few peaks. We then perform another Gaussian convolution to "smooth out" this vector, making the scoring system forgiving of slightly missed notes. Finally, we calculate the cosine similarity to determine the score.

To determine the difficulty of the scoring algorithm, we have two knobs we can turn. To change the timing resolution, we can change the window size. A larger window will result in lower timing accuracy, but increased frequency resolution. To complement this, by increasing the blur size we can lower the penalty for missing notes slightly.
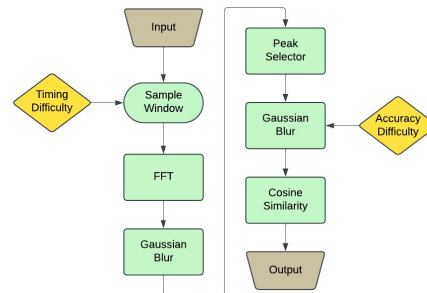
User Interface

Upon launching the game, users are greeted with a home screen where they can select a song using the arrow keys and ENTER key. After selection, the gameplay screen provides visual cues, with color-coded notes falling down six lanes representing guitar strings. Players must match the notes at the indicated times, while the scoring system runs in the background, calculating performance in real time and presenting the final score at the end of the song. Shown below is a beta version of our User interface.
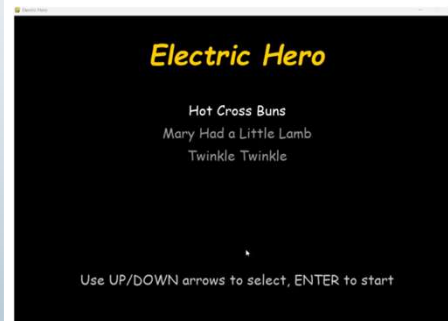
Main menu screen

Gameplay

Scoring screen

Societal Impact

Electric Hero provides an accessible and innovative way for individuals to engage with music education through interactive gameplay. By combining real-time guitar performance with intuitive visual feedback, the system encourages users to develop musical skills such as timing, note recognition, and rhythm. As the education system faces increasing budget cuts and teacher shortages, this project offers a promising example of how embedded systems and digital signal processing can create engaging, affordable learning tools accessible beyond traditional classroom settings. In the future, Electric Hero could serve as the foundation for low-cost, gamified music education platforms, helping to expand access to music lessons, support cognitive development, and promote cultural appreciation across diverse communities.

Future Work

As a framework, Electric Hero can be greatly expanded to widen our societal impact. Because we compare signals directly, we could use this same software for a whole wide range of instruments. We selected electric guitar for availability reasons and ease of input, but the general principle should apply to any instrument or even to vocals.

One of the easiest ways to expand this project would be to incorporate more tracks. Our current way of creating tracks needs an audio file as well as a file that effectively stores note timings. A more sophisticated system could analyze an audio file of a guitar solo to extract the note timings automatically. An even more elaborate system could separate out the guitar part from a multi-instrument recording, then create note timings.

Another way to extend this project would be improving the note matching system with a machine learning model. Some common audio classification models turn the frequency data into a spectrogram, then run sophisticated (and better-researched) image classification models to extract information. Such an approach could be used for this project to make an even more robust system for note classification and/or matching.

To help facilitate some of this future work and to align with our goals, we will make the code for Electric Hero publicly available to allow for free access and further development.

Acknowledgements