Manipulating amplitude of acoustical sound waves in order to alter timbre

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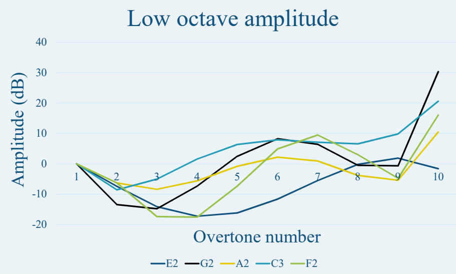
Introduction

Every musical tone consists of a harmonic series of overtones that are characterized by the amplitude of each overtone. The timbre of every note from each instrument forms a remarkably different waveform due to the difference in amplitude of the overtone series. This is what causes timbral differences between instruments, which is why instruments sound different playing the same note. Timbre is defined as all characteristics of sound that are not pitch or intensity. The timbral qualities of an electric guitar differ from an acoustic guitar because "(1) its body does not vibrate much, and (2) the string output is recorded by pick-up microphones placed under the strings" (Traube, 2000). The purpose of this study is to derive a series of algorithms that can change the waveform of an electric guitar into the waveform of an acoustic guitar, thereby giving them similar timbral qualities.

Materials and Methods

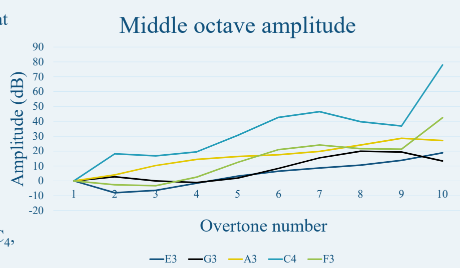
First, the notes E, G, A, C, and F were recorded in the low, middle, and high octaves on the electric guitar and acoustic guitar. The recordings were then imported into WavePad FFT Sound Analyzer™. Next, the instant of attack was calculated for each of the notes and a Fourier transform was performed exactly 0.4 seconds after the attack of the note. This time increment was used in order to improve the ease of reading the peak heights. If the Fourier transform was performed at the moment of the attack, the peaks would not yet be established, making them more difficult to read. On the other hand, it was found that if too much time passed between the attack of the note and duration of the note, it would decay and the amplitude values would not be accurate. Then, the amplitude was measured at the first 10 peaks of the Fourier transform graph for each note. The peak heights were then normalized in order to make the volume of the notes equal for comparison. Next, the normalized peak heights for overtones 1-10 were graphed on the same plot, along with the difference between the two sounds (Acoustic – Electric). Following this, a 5^{th} degree polynomial was derived in order to most accurately fit the difference between the acoustic and electric sound. Lastly, the percent reduction in decibel difference between the acoustic and the algorithmically modified electric sound was calculated. The goal of the project was to be able to reduce the timbral difference in decibels by an average of at least 50%.

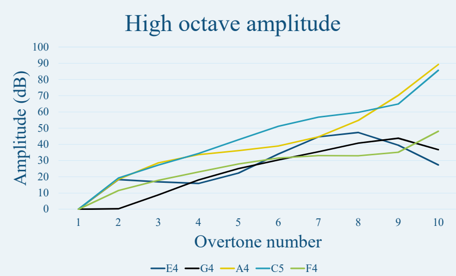
Results



Graph 1 (left): The amplitudes at each overtone number represent the algorithmic value derived from a fifth degree polynomial that is added to the amplitude of the electric guitar waveform in order to simulate the amplitude of the acoustic guitar waveform at that overtone. Provided are the algorithmic values that were created for the notes E_2, G_2, A_2, C_3, and F_2.

Graph 2 (right): The amplitudes at each overtone number represent the algorithmic value derived from a fifth degree polynomial that is added to the amplitude of the electric guitar waveform in order to simulate the amplitude of the acoustic guitar waveform at that overtone. Provided are the algorithmic values that were created for the notes E_3, G_3, A_3, C_4, and F_3.

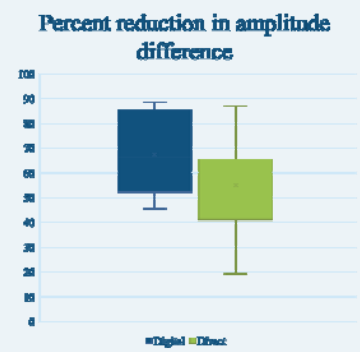




Graph 3 (left): The amplitudes at each overtone number represent the algorithmic value derived from a fifth degree polynomial that is added to the amplitude of the electric guitar waveform in order to simulate the amplitude of the acoustic guitar waveform at that overtone. Provided are the algorithmic values that were created for the notes E_4, G_4, A_4, C_5, and F_4.

Through error analysis of the notes recorded using an auxiliary cord and the notes recorded using a Shure 57 instrumental microphone, the created algorithm was found to reduce the difference between amplitudes by an average of 61%. The algorithms that were derived for the digitally recorded notes with the auxiliary cord were able to reduce the amplitude difference by an average of 67%, while the notes recorded using the instrumental microphone were able to reduce the amplitude difference by an average of 55% (See Graph 4).

Results (cont.)



Graph 4 (left): The algorithms pertaining to the notes that were recorded digitally using an auxiliary cord had an overall higher percent amplitude difference reduction than the algorithms correlated with the notes that were directly recorded using an instrumental microphone. For the digitally recorded notes, the highest and lowest percent reductions were 88% and 46%, respectively. The directly recorded notes had the highest percent amplitude difference reduction at 87%, with the lowest percent reduction at 19%.

Conclusions

The purpose of this study was to create a series of fitting curves that would make an electric guitar simulate the timbre of an acoustic guitar. This purpose was met since the error was significantly reduced through algorithm derivation. Through applications of the derived algorithms, it was found that the algorithms applied were able to reduce timbral differences between electric and acoustic by approximately 61%, which is a greater reduction in amplitude difference than the goal. This strongly suggests that a more efficient and more accurate fashion of electronic sound simulation is possible.

This project is the first step to creating a more efficient means of altering acoustical sound waves. By providing the algorithms that allow for the alteration of the timbre of the electric guitar, future projects can be envisioned to enhance this idea and develop a program to apply this theory and demonstrate the effect acoustically. This idea can be expanded to encompass a large array of musical instruments, making this method of timbral alteration possible for all notes.

References

Traube, C., & Smith, J. O. (2000, December 7-9). *Estimating the plucking point on a guitar string.* Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.419.6326&rep=rep1&type=pdf