Audio Spectrum Analysis of Natural Harmonics on a Vibrating Guitar String

Madeline Jennings, Isaac Khan, Phawat Leechesan

Cornell University

Abstract

This project investigates the characteristics of natural harmonics on a vibrating guitar string. Our goal was to analyze the conditions under which they occur (namely, how the thickness, tension and and playing position of the string affect the resultant sound). We used a Fast Fourier Transform (**FFT**) to analyze the harmonics produced on each fret of each string and found that **[1]** the frets where harmonics occur are the same for each string. We further found that **[2]** harmonics on these frets form the same interval from the open string across all strings, and **[3]** the presence of a harmonic on a given fret can be predicted by its proximity to **standing wave** nodes.

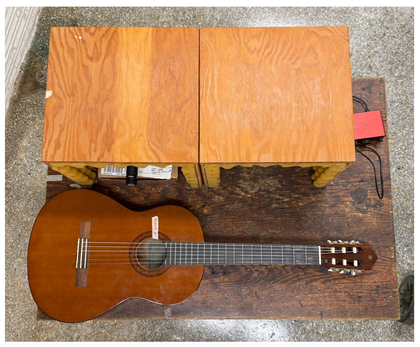
Introduction

Guitarists have observed that plucking a string while lightly pressing it above a fret wire causes major changes in the resultant sound. In some cases, the fingering deadens the string, muting it almost entirely, and at other frets, a **natural harmonic** emerges. Natural harmonics have a distinct, bell-like tone, different from the sound produced by normal fretting. To hear an **example** of a *harmonic* and a *dead string*, scan the QR code below.

The harmonics on different frets vary greatly in their tonal qualities, and it is not at first obvious to predict which frets will produce strong harmonics or their component frequencies. Some may produce a sound an octave higher than from normal fretting, while others produce sounds that differ by another interval.

Experiment

For each fret on each string of the guitar, we attempted the mechanism that produces the natural harmonic. We did this about 10 times for each fret, as sometimes the mechanism is not properly achieved on the first try. The resultant sound was recorded on a Shure SM57 microphone and stored in .flac format. The area surrounding the microphone was soundproofed to minimize background noise, and the location of the guitar relative to the microphone as well as the plucking position were held constant throughout the experiment. Some supporting measurements were taken, such as the position of each fret (in cm) along the string, and other qualities such as the diameter, material and tension on each string could be found on the container. The figure below is of the **experimental setup**.



After reviewing the audio clips and flagging recordings with audible harmonics, a clearest recording was selected from each, of the 10 or so trials. This is simply the instance with the least background noise and the loudest harmonic. A FFT was then performed using NumPy on each recording to determine its constituent frequencies and their respective amplitudes.

Results

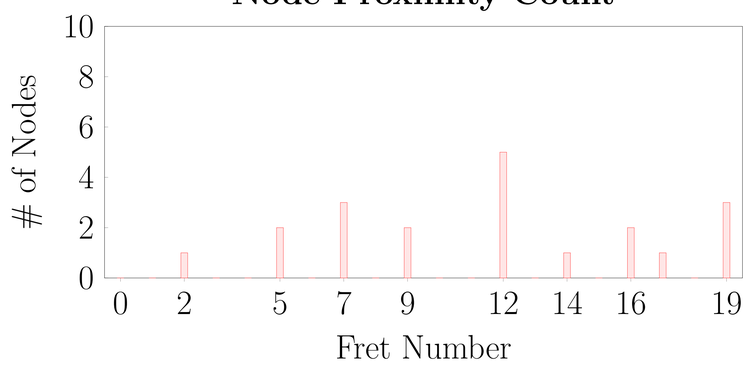
The most immediate observation, prior to performing any FFT, was that the frets along the string with audible harmonics were the same for each string. Though their constituent frequencies differed, the intervals between the harmonics and the frequency of the open string were consistent across strings as well. For example, the most audible harmonic frequency on the 5th fret of the low E string is roughly 325Hz (E4), which is two octaves above the open string. On the 5th fret of the D string, it is roughly 577Hz (closest to D5), which is also two octaves above the open string.

Fret	Interval From Open String
4	M3
5	Octave (x2)
7	P5
9	M3
12	Octave
16	M3
19	P5

A table of the frets with audible harmonics and their **intervals** from the open string is shown above.

Discussion

The widely accepted hypothesis that frets closer to standing wave nodes will have prominent harmonics is supported by our data. The graph below shows the number of **nodes** within 0.5% of the string's *length* to a given **fret**. The frets with high node counts (19, 12, 7) have clear harmonics with strong frequencies in their FFT plots that stand out from noise. It is evident that the **length** of the string impacts where along the string harmonics will occur, *as opposed to* the tension, mass or thickness, which seem to impact the **frequencies** of the harmonic instead.



Conclusion

Our analysis has led to several key conclusions:

1.) Natural harmonics occur at the same frets for each string.

2.) The intervals between a fret's harmonic and the open string are invariant across strings.

3.) The presence of a fret's harmonic can be predicted reasonably well by the distance from the fret to a node.

One interesting area of research for future investigators would be to examine the dynamics of **artificial** harmonics, colloquially known as "pinch" harmonics. These are performed on an electric guitar with a special picking technique, and produce very different results.

Additional Reading

More data, measurements, audio recordings, and code used in this project can be found at our GitHub repo: https://github.com/zhav0ronok/phys2210-final