Signal Processing Analyses of the Effects of Guitar Geometry on Musical Timbre

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Abstract: Three guitars of varying shapes, a box, triangle, and octagon, were constructed and compared to a traditional “figure-eight” guitar sound box. The geometries of the sound boxes were varied, while the volume and materials were kept approximately constant. A survey was conducted to assess listeners' preferences for the musical timbre of the instruments. Digitized samples of the six plucked strings were obtained for all four guitars. Conventional power spectral density (PSD) Fourier analysis of the notes showed similarities. A number of other signal analysis methods were employed including, inverse transform of principal harmonics, measures of spectral difference, and short-time Fourier transforms (STFT). Methods such as the STFT are valuable for following the time course of the frequency components in a transient or time-varying signal. The aim of this project was to identify those features of geometry and spectrum which have an effect on the perceived guitar timbre. It also served as an excellent tool for engineering education and the many interdisciplinary aspects of acoustics, musical acoustics, psychoacoustics, and signal processing.

INTRODUCTION

This undergraduate project was intended to introduce students to a number of research questions in acoustics. The first general question was how the geometry of a musical instrument affects its timbre and the perception of tones by general listeners. This involved design, materials science, and an introduction to psychoacoustics (1-6). It was determined to keep materials and sound box volume relatively constant and to focus on the geometry of the sound box and its affect on subjective and objective measures of instrument timbre. The second phase of the project was to apply various signal processing methods to determine if spectral qualities of the signal were related to instrument geometry and listener preference. This involved digital signal processing and computer programming in the MATLAB® platform (7-9).

Plywood was used to build the sound boxes of the guitars, without inner bracings. After the frames were complete, flat boards were used as the front and back plates. The plates were glued to the frames. Before placement of the top plates, a 3 inch diameter circular sound hole was cut. The neckpiece was purchased ready-made, and made interchangeable with each of the sound boxes. The sound boxes were stained and the neckpiece was coated with 5 coats of black spray enamel. Standard guitar strings, tuning pegs, and bridges were also purchased and applied to the instruments. A digital tuner with a built-in microphone was used to tune the notes E6, A5, D4, G3, B2, and E1 to a precision of +/- 1%. Plucked tones from each guitar and guitar string (24 different samples) were taken with an Ensoniq™ EPS 16 digital sampler. The tones were sampled at 44 kHz with a 16 bit A/D conversion resolution.

SUBJECTIVE ANALYSIS - SURVEY

After the tones were sampled onto the keyboard, the samples were placed on an audio tape in random order for the psychoacoustic survey. Six combinations of the four guitars are possible for note-by-note comparison. With six strings on each guitar to compare, a total of 36 two-way comparisons were created. Those 36 combinations were presented to a small cohort of listeners to determine sound preference. The survey lasted about 20 minutes and included questions about participants' musical background and listening preferences. The surveys from this limited group showed that the most satisfying tones were those from the octagon-shaped guitar. This was slightly preferred to the traditional figure-eight guitar, which was followed by the box and triangular-shaped models. There seems to be a correlation between tone preference and tone "ringing". Those tones with more cycles of ringing were least preferred. Preliminary results also suggest that the guitars with more uniformly distributed high frequency amplitudes were most preferred.

OBJECTIVE ANALYSES - SIGNAL PROCESSING APPROACHES

The Ensoniq™ samples were also processed into 8 bit * WAV files, which can then be easily accessed by MATLAB® routines for analysis. The general goal of this portion of the project was to apply digital signal processing techniques (DSP) and various signal representations in order to gain insight into possible unique, objective measures of sound quality. The types of analyses performed were as follows: (1) time domain plots (Fig. 1a), (2) power spectral density (PSD) plots (Fig. 1b), computed as the squared magnitude of the Fourier transform...
over the entire recording time interval, and thus provided no information about the time-varying characteristics of
the tones, (3) short-time Fourier transform (STFT) or spectrogram plots represented in both two and three
dimensions (Fig. 1c), which provided some information about the time course of the transient tones, (4) plots of the
first three (principal) harmonics of the fundamental frequency of the string plotted in the time domain, as
determined from the relative magnitudes of spectral components, (5) spectral difference plots, as computed
differences between each of the sample guitars' PSD and the standard model's PSD, and (6) signal reconstruction
plots, both as an inverse Fourier transform (IFFT) of the spectrogram (Fig. 1d) and an inverse transform based
solely on the three principal harmonics. A few representative plots of some of these different kinds of analyses are
presented in the figures below. The signal computed from the IFFT (Fig. 1d) is different from the original (Fig. 1a)
as a result of the unavoidable DSP windowing used to weight the data. Wavelet analysis might prove a better
choice with its ability to vary temporal and spectral resolution according to the amount of detail in the signal.
Wavelet and cross-correlation analyses are being conducted for comparison with the methods already used.

FIGURE 1. Results for the first string, E1, of the box-shaped guitar. (a) Time domain plot of the plucked string. (b) PSD plot
shows overall spectrum with fundamental frequency at 328 Hz. (c) 3D-Spectrogram plot using a windowed FFT algorithm.
Time course of transient response can be studied. (d) Inverse FFT of spectrogram in (c). Similar to original signal in (a), but
some information is lost.

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REFERENCES