Quantitative Analysis of Guitar Harmonic Character

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Abstract

In this experiment, guitar sound clips will be taken, analyzed, edited, and rated to attempt to find a correlation between the harmonic content of musical timbre and the rating of a listener. This will be accomplished by isolating the harmonic content of the guitar sound, rating the clips, and modeling the ratings as a function of the harmonic content.

Introduction

Timbre, the "color" aspect of sound, has largely eluded quantification [1-2]. Timbre has many elements, some of which include attack, decay, harmonic balance, audible inharmonicity, and vibrato, all of which are time-dependent[2,3-7,25]. Many methods have been developed to analyze this aspect have been devised. Fourier analysis, the most classic example, has been used for years to deconstruct the oscillations of a sound wave into its parent sine waves, each of which coincide with an overtone [8-15]. Other tests, such as spectrograms, scalograms, pseudodifferential operators, Heisenburg analysis, amplitude-envelope-analysis, instantaneous frequency analysis, etc. [9,11,13,14,16, 17]. This article will focus predominantly on Fourier analysis and spectral analysis.

Timbre has long been related to musical quality [18]. As such, both instrument-makers and those wishing to model those instruments have always spear-headed the research into this field. The harmonic content of the instrument will be the center of this study. As such, other elements need to be minimized, such as attack and decay (mainly attack) and polyphony, as the analysis could be made less representative [3,19,20,24]. Additionally, problems arise from relating the qualitative analysis of guitar tone to the quantitative analysis. This issue is largely resolved by the method of paired comparisons [21]. The performance of the sound clip for subjective analysis, in order for the method to work, must be as identical as possible, as musical elements more apparent than timbre could be used to rate the clips; as such, minimal stylistic playing should be used, and the acoustic environment should be minimal (low acoustics, consistent reverb levels, etc.) [22-23,26,28].

From the data received from the voting, a model will be constructed denoting the rating versus harmonic content [27].

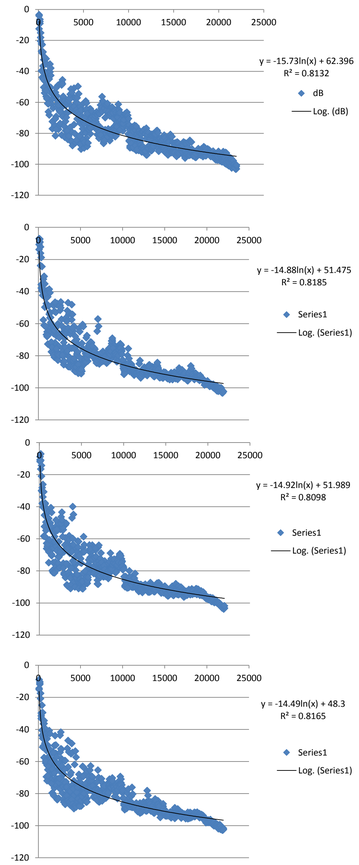
Experiment

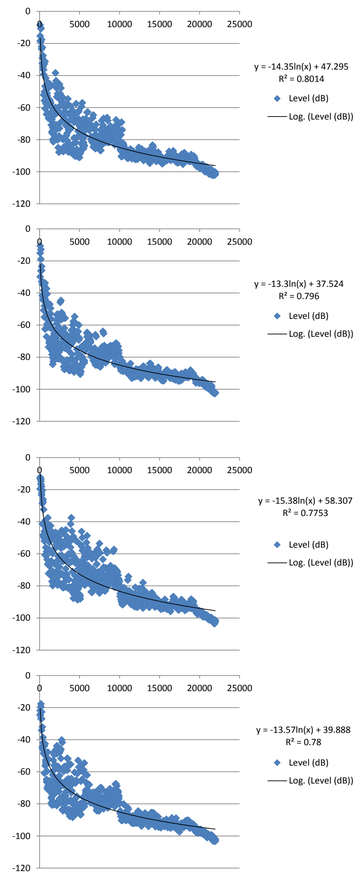
Guitars of various different makes and materials will be recorded. From that recording clip, the attack of the guitar will be clipped out of the file. After that, a very brief sound segment will be cut. This sound clip will serve as the fundamental for analysis. This sound file will be run through an FFT (Fast Fourier Transformation) program to generate a spectrum of its harmonic components. The data points will then be used to generate a function describing the harmonic content of each guitar. The slopes of these functions will be used for comparison (Harmonic Content Slope, or HCS). These measurements will be taken three times per instrument, once at the first fret, once at the fifth fret, and once at the twelfth fret. This concludes the measurement phase. The data points for all three frets will be totaled, and this graph will be used for comparison.

The sound clips used for the analysis will be duplicated and inserted sequentially, creating a single continuous pitch per position per instrument. This will make a total of three pitches per instrument.

Experienced musicians will then be asked to blindly rate the timbre of each instrument, with each sound clip available at once (paired comparisons).

A statistical model of the average ratings of the guitars versus their HCS will be generated. From this model, a trend between HCS and average timbre rating will be generated (if one exists).

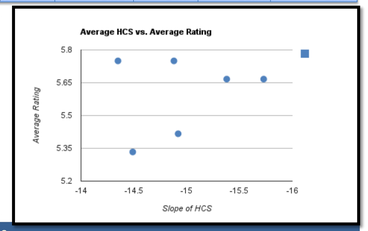




These are graphs of HCS ratings. Hz are displayed on the x-axis, and dB are displayed on the y-axis.
Column 1: Guitars 1-4
Column 2: Guitars 5-8

Guitar #	Guitar	Back and Side wood	top wood	1st slope	5th slope	12th slope	overall slope
1	Taylor 214	Rosewood	Spruce	-15	-16.54	-15.64	-15.73
2	Martin OOO MMV	Rosewood	Spruce	-15.11	-15.02	-14.5	-14.88
3	Gibson RS29ANNH1WC-J29	Rosewood	Spruce	-15.85	-14.61	-14.29	-14.92
4	Yamaha A1MHC Dreadnought cutaway	Mahogany	Spruce	-14.47	-15.53	-13.47	-14.49
5	Martin GPCPA5	Mahogany HPL	Spruce	-15.24	-13.77	-14.04	-14.35
6	Martin D15M	Mahogany	Mahogany	-13.94	-13.42	-12.54	-13.3
7	Taylor 114e	Sapele	Spruce	-16.54	-15.51	-14.18	-15.38
8	Yahama LS6RL	Rosewood	Spruce	-15.28	-14.04	-11.39	-13.57

The final graph, showing, unfortunately, no definitive correlation one way or another.



Discussion

After the data was collected and modelled, it became apparent that there was no obvious correlation between HCS and listener rating.

One reason for this could be that harmonic inharmonicity and harmonic harmonicity were not considered in this experiment. This means that a guitar that has dissonant harmonics (caused possibly by bad intonation of the guitar saddle or frets), which could have the same HCS as a guitar with excellent harmonics. This could confound the data, as there was no way to allot for this.

Another problem with this experiment was simply how few responses were received. This experiment, aimed at looking at overall preferences in a massive population, could have benefitted from having many more responses (possibly even thousands before getting a truly representative survey). With only twelve responses, this survey was incredibly limited.

Overall, however, the experiment, even under perfect conditions, could have behaved very similarly to this one. Guitars with more harmonic content were tended to be slightly more favored against those with lower levels. Additionally, guitars with rosewood back and sides typically had higher HCS ratings than, say, mahogany. Then it makes sense that guitar stores generally keep more rosewood guitars stocked than those made of mahogany, which is often the case.

Acknowledgements

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References

[1] Benade HA (1990) *Fundamentals of Musical Acoustics*. Dover Publications.
[2] *Timbre: Sound Quality*. http://hyperphysics.phy-astr.gsu.edu/hbase/sound/timbre.html.
[3] Fletcher NH and Rossing TD (1998) *The Physics of Musical Instruments*. Springer Science+Business Media Inc.
[4] Benade AH (1990) *Fundamentals of Musical Acoustics*. Dover Publications.
[5] Erkut C and Välimäki (2000) *Model-Based Sound Synthesis of a Tanbur, a Turkish Long-Necked Lute*. IEEE
[6] Wessel DL. *Timbre Space as a Musical Control Structure*. Paris, France.
[7] Grey JM (1975) *An Exploration of Musical Timbre*. Stanford University.
[8] Williams EG (1999) *Fourier Acoustics: Sound Radiation and Nearfield Acoustical Holography*. Academic Press.
[9] Krantz SG (2009) *Explorations in Harmonic Analysis: With Applications to Complex Function Theory and the Heisenburg Group*. New York.
[10] Hughes JR (2000) *Applications of Fourier Series in Classical Guitar Technique*. September College Mathematics Journal.
[11] Alm JF and Walker JS (2002) *Time-Frequency Analysis of Musical Instruments*. Society for Industrial and Applied Mathematics.
[12] Forster C (2010) *Musical Mathematics: On the Art and Science of Acoustic Instruments*.
[13] French RM (2009) *Engineering the Guitar: Theory and Practice*. Springer Science+Business Media, LLC.
[14] Ethington R and Punch B (1994) *SeaWave: A System for Musical Timbre Description*.
[15] Rossing TD (1990) *The Science of Sound*. Addison-Wesley Publishing Company.
[16] Sueur J (2014) *Seewave: A Very Short Introduction to Sound Analysis for Those Who Like Elephant Trumpet Calls or Other Wildlife Sound*. Muséum National d'Histoire Naturalle.
[17] Kopeč J and Sali Š (2000) *Measuring the Quality of Guitar Tone*. Experimental Mechanics.
[18] Zukofsky P 91968) *On Violin Harmonics*. From *Perspectives of New Music*, Volume 6, #2, Princeton University Press.
[19] Hall DE (2002) *Musical Acoustics, 3rd Edition*. California State University.
[20] Lewis R et al (2010) *Blind Music Timbre Source Isolation by Multi-resolution Comparison of Spectrum Signatures*.
[21] David HA (1963) *The Method of Paired Comparisons*. Hafner Pub. Co.
[22] Russel BE (2010) *The Development of a Guitar Performance Rating Scale using a Facet-Factorial Approach*. Board of Trustees, University of Illinois.
[23] Erkut C et al (2001) *Methods for Modeling Realistic Playing in Acoustic Guitar Synthesis*. MIT.
[24] Järveläinen H and Tolonen T. *Perceptual Study of Decay Parameters in Plucked String Synthesis*. Helsinki University of Technology, Laboratory of Acoustics and Audio Signal Processing, Espoo, Finland.
[25] Tolonen T. *Object-Based Sound Source Modeling for Musical Signals*. Helsinki University of Technology, Laboratory of Acoustics and Audio Signal Processing, Espoo, Finland.
[26] Pakarinen J. *Physical Modeling of Falgeolet Tones in String Instruments*. Helsinki University of Technology, Laboratory of Acoustics and Audio Signal Processing, Espoo, Finland.
[27] Jánosy Z et al. (1993) *Towards High-Quality Sound Synthesis of the Guitar and String Instruments*. Tokyo, Japan.
[28] Chowning JM et al. (1974) *Computer Simulation of Music Instrument Tones in Reverberant*. Artificial Intelligence Laboratory, Stanford University.