A Timbre Attribute Calculator and Music-Analytical Applications

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Objectives

Musical tension is well-understood for pitch, but not for other parameters such as timbre. To better understand how timbre relates to dissonance, I built a Matlab calculator for potentially relevant quantitative timbre attributes and compare the resultant values to a preexisting musical analysis of a twentieth-century piece.

Introduction

In much modern classical music, timbre is of equal importance to pitch, but it is not as well-understood in terms of form and tension. Music perception researchers often describe timbre using both statistical properties of the spectrum, such as spectral centroid, spectral spread, and spectral flatness, as well as by extracting peaks and treating the resulting frequencies as a chord, such as in roughness and inharmonicity.

Higher values of all five of those attributes are at least sometimes associated with higher musical tension, both in perception-oriented [1, 2, 3] and more speculative [4, 5, 6] literature.

Figure 1 shows the Matlab interface I constructed to the calculator for these timbre attributes. The upper two plots contain a waveform display and spectrogram; the lower plot contains the timbre attributes chosen by the user according to the checkboxes at top right.

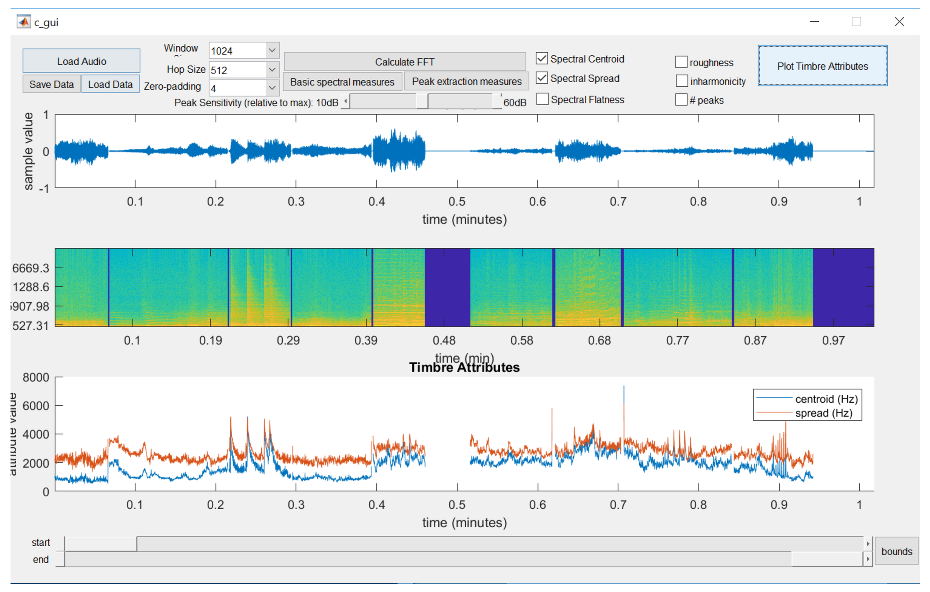

Figure 1:Matlab interface

Statistical Attributes

Spectral Centroid, Spread (Standard Deviation), and Flatness, are all calculated directly from the spectrum of each frame. Formulae are from [7, 1, 8, 9].

Spectral centroid corresponds to "brightness" through mean frequency:

$$SC = \mu_1 = \frac{\sum_{k=1}^{K} f_k a_k}{\sum_{k=1}^{K} a_k}$$

Sprectral spread is the corresponding standard deviation:

$$SS(D) = \mu_2 = \frac{\sqrt{\sum_{k=1}^{K} (f_k - \mu_1)^2 a_k}}{\sum_{k=1}^{K} a_k}$$

Spectral flatness measures similarity to white noise:

$$SFM = \frac{\sqrt[K]{\prod_{k=1}^{K} a_k}}{\frac{1}{K}\sum_{k=1}^{K} a_k}$$

Peak-Based Attributes

Timbre and inharmonicity are more difficult to directly calculate as they require peak extraction, but are more frequently associated with traditional notions of consonance and dissonance [10]. These formulae are from [1, 9, 7, 5, 6, 11].

Inharmonicity measures the distance of peaks from the harmonic series above an extracted fundamental:

$$I = \frac{2}{f_0} \frac{\sum_{n=1}^{N} |f_n - n f_0| a_n^2}{\sum_{n=1}^{N} a_n^2}$$

Roughness of a sound is the sum of the "roughness" between any pair of peaks, which is dependent on their spacing in critical bandwidths:

$$\rho = \sum_{j=0}^{n} \sum_{k=1}^{n-1} \frac{a_j a_k g(f_{cb})}{a_j^2}$$

$$f_{cb} = \frac{f_i - f_j}{1.72(\frac{f_i + f_j}{2})^{0.65}}$$

$$g(f_{cb}) = (4e f_{cb} e^{-4 f_{cb}})^2$$

Methods

Based on my own music-analytical research, certain sounds in Sofia Gubaidulina's *Meditation on a Bach Chorale* were identified as consonant and dissonant. I created 1-minute audio files consisting of a series of consonant sounds, a pause, and a series of dissonant sounds, all drawn from a given recording. I used three different recordings of the piece. These audio files were put into a Matlab calculator for the timbre metrics just described.

Results

As shown in Figure 2, in which consonant sounds are on the left and dissonant sounds on the right, musical tension often correlates with higher spectral centroid and spectral flatness, and sometimes with higher spectral spread. However, inharmonicity and roughness were too highly variable to be descriptively useful.

Figure 2:Positive results

Result

Musically dissonant timbres generally had higher spectral flatness and spectral centroid (in Gubaidulina's *Meditation* specifically). Other timbre attributes were less consistently useful.

References

[1] Morwaread M. Farbood and Khen C. Price. The contribution of timbre attributes to musical tension. *The Journal of the Acoustical Society of America*, 141(1):419–427, January 2017.

[2] Daniel Pressnitzer, Stephen McAdams, Suzanne Winsberg, and Joshua Fineberg. Perception of musical tension for nontonal orchestral timbres and its relation to psychoacoustic roughness. *Perception & Psychophysics*, 62(1):66–80, January 2000.

[3] William A Sethares. Local consonance and the relationship between timbre and scale. *The Journal of the Acoustical Society of America*, 94(3):1218–1228, 1993.

[4] Fred Lerdahl. Timbral hierarchies. *Contemporary Music Review*, 2(1):135–160, January 1987.

[5] John MacCallum and Aaron Einbond. Real-Time Analysis of Sensory Dissonance. In *Computer Music Modeling and Retrieval. Sense of Sounds*, Lecture Notes in Computer Science, pages 203–211. Springer, Berlin, Heidelberg, August 2007.

[6] John MacCallum, Jeremy Hunt, and Aaron Einbond. Timbre as a psychoacoustic parameter for harmonic analysis and composition. In *ICMC*, 2005.

[7] Geoffroy Peeters, Bruno L. Giordano, Patrick Susini, Nicolas Misdariis, and Stephen McAdams. The Timbre Toolbox: Extracting audio descriptors from musical signals. *The Journal of the Acoustical Society of America*, 130(5):2902–2916, November 2011.

[8] Derry FitzGerald and Jouni Paulus. Unpitched percussion transcription. In *Signal Processing Methods for Music Transcription*, pages 131–162. Springer, 2006.

[9] Perfecto Herrera, Anssi Klapuri, and Manuel Davy. Automatic Classification of Pitched Musical Instrument Sounds. pages 163–200. January 2006.

[10] James Tenney. A history of 'consonance' and 'dissonance'. 1988.

[11] Richard Parncutt. *Harmony: A psychoacoustical approach*, volume 19. Springer Science & Business Media, 2012.