Roughness Calculation Model (from Vassilakis, 2001 & 2005)

BACKGROUND

Numerous roughness calculation models have been proposed over the last ~100 years (*e.g.* Helmholtz, 1885; Plomp & Levelt, 1965; Kameoka & Kuriyagawa, 1969a&b; Hutchinson & Knopoff, 1978; Sethares, 1998), largely overlooking the two principal studies (von Békésy, 1960; Terhardt, 1974) that have systematically examined the relationship between a signal's amplitude fluctuation degree and roughness. They have been employed in studies that attempt to link auditory roughness to auditory/sensory consonance (*e.g.* Vos, 1986; Bigand *et al*., 1996; Dibben, 1999), demonstrating a relatively low degree of agreement between calculated and experimental data.
All the above models (review in Vassilakis, 2001):
(a) overestimate the contribution of sound pressure level (i.e. absolute amplitude values of the interfering signals) to roughness,
(b) underestimate the contribution of the degree of amplitude fluctuation (i.e. relative amplitudes values of the interfering signals) to roughness, and
(c) often misrepresent the relationship between roughness and register.

SRA incorporates a new roughness calculation model, outlined below. Perceptual experiments testing the model indicate that it reliably and validly represents the perception of roughness, and performs better than previous roughness calculation models (Vassilakis, 2001, 2005).

ROUGHNESS OF SINE-PAIRS

Note: *As is the case with all roughness calculation models, the absolute roughness values calculated by the model are arbitrary and are only useful for roughness comparisons among signals that have been analyzed using consistent analysis parameters*.

The roughness **R** of a signal whose spectrum has two sinusoidal components with frequencies f_1, f_2 and amplitudes A_1, A_2, where $f_{\text{min}} = \min(f_1, f_2)$, $f_{\text{max}} = \max(f_1, f_2)$, $A_{\text{min}} = \min(A_1, A_2)$, $A_{\text{max}} = \max(A_1, A_2)$, is:

$\mathbf{R} = \mathbf{X}^{0.1} * \mathbf{0.5}(\mathbf{Y}^{3.11}) * \mathbf{Z}$ where

$\mathbf{X} = A_{\text{min}} * A_{\text{max}}$
The term $\mathbf{X}^{0.1}$ represents the dependence of roughness on intensity (related to the amplitude of the added sines). It is based on Terhardt (1974), adjusted (Vassilakis, 2000, 2001) to account for the quantitative difference between modulation depth (used in Terhardt, 1974) and amplitude fluctuation degree (the signal parameter influencing roughness).

$\mathbf{Y} = 2A_{\text{min}} / (A_{\text{min}} + A_{\text{max}})$
The term $\mathbf{Y}^{3.11}$ represents the dependence of roughness on amplitude fluctuation degree (related to the amplitude difference of the added sines). It, too, is based on Terhard (1974), adjusted (Vassilakis, 2000, 2001) to account for the quantitative difference between modulation depth and amplitude fluctuation degree.

$\mathbf{Z} = e^{-b1s(f\text{max} - f\text{min})} - e^{-b2s(f\text{max} - f\text{min})}$,
[$b1 = 3.5$; $b2 = 5.75$; $s = 0.24/(s1 f_{\text{min}} + s2)$; $s1 = 0.0207$; $s2 = 18.96$]
The term **Z** represents the dependence of roughness on amplitude fluctuation rate (frequency difference of the added sines) and register (frequency of the lower sine). It is based on Sethares's (1998) modeling of the roughness curves in Figure 1, below, curves that have been derived from multiple perceptual experiments examining the roughness of pairs of sines (Plomp & Levelt, 1965; Kameoka & Kuriyagawa, 1969a&b).

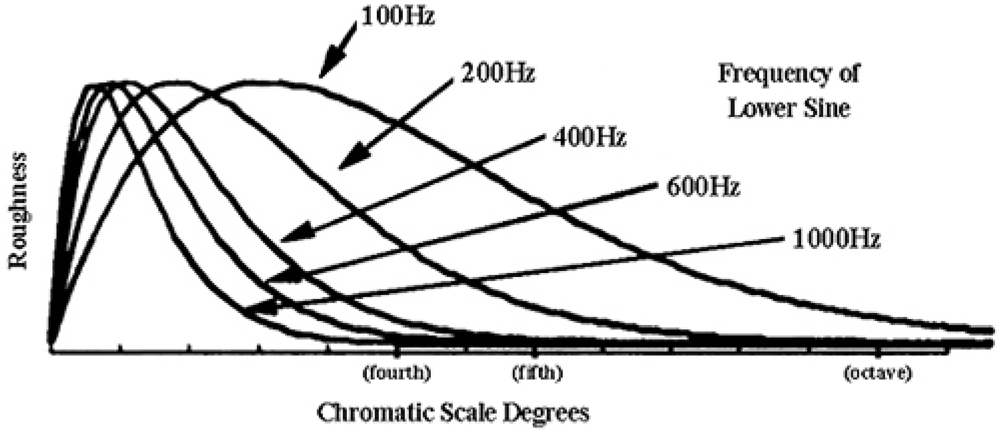

Figure 1: Roughness curves plotting the observed roughness (arbitrary measure - y axis) of a pair of sines (equal amplitudes) as a function of frequency separation (x axis) and frequency of the lower sine (after Sethares, 1998: 45). The roughness curves have been derived from multiple perceptual experiments examining the roughness of pairs of sines (Plomp & Levelt, 1965; Kameoka & Kuriyagawa, 1969a&b).

ROUGHNESS OF SIGNALS CORRESPONDING TO SPECTRA WITH MORE THAN TWO COMPONENTS

The roughness of signals corresponding to spectra with more than two sine components is calculated by summing the roughness of all sine-pairs in the spectrum. Although it has been argued that, depending on the relative phase of the respective amplitude fluctuations, the total roughness can be less than the sum of the roughness values for individual sine-pairs (von Békésy, 1960: 350-351), several studies (*e.g.* Terhardt, 1974; Lin & Hartmann, 1995) and pilot experiments (in Vassilakis, 2001) indicate otherwise. More specifically, Lin & Hartmann (1995) concluded that the total roughness is summed over all auditory filters. In addition, since roughness modeling is meaningful to roughness comparisons among multiple signals, rather than to roughness calculations of isolated signals, any such phase effects are more likely to be diffused across the signals of interest, the more complex the signals (see also below).

ROUGHNESS CALCULATION AND PHASE OF A SIGNAL'S SPECTRAL COMPONENTS

The phase of a signal's spectral components is not included as a parameter in the roughness calculation. According to Pressnitzer & McAdams (1999), the relative phase of the components of a three-component spectrum influences the complex signal's overall envelope shape and/or amplitude fluctuation degree, consequently influencing the signal's roughness, especially when three or more sine components fall within the same critical band.
In spite of this observation, the absence of the phase parameter from the model does not significantly distort the model's calculations. For the types of signals that will be submitted to the calculator (synthetic signals, where the phase relationship of the components can be controlled and remain the same for all, or natural signals from polyphonic passages, where the phase relationships are more likely to be random than systematic), differences in the roughness phase effects among the signals to be examined are either controllable or defused. This supports valid comparisons of the resulting relative roughness values.
As is the case with all roughness calculation models, the absolute roughness values calculated by the model are arbitrary and are only useful for roughness comparisons among signals that have been analyzed using consistent analysis parameters.

ROUGHNESS CALCULATION AND LOUDNESS

The model does not adjust for equal loudness.

ROUGHNESS MODEL CALCULATIONS VS PERCEPTUAL ROUGHNESS RATINGS

The roughness calculations of the model correlate very well (r = 0.98) with roughness ratings obtained in a set of perceptual experiments (Vassilakis, 2001 & 2005), better than predictions of models by Helmholtz, 1885 (r = 0.73) and Hutchinson and Knopoff, 1978 (r = 0.87).

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(with some links to the sources)

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