Generating Simultaneous Dyads with Harmonic Spectra and Calculating their Roughness

The following account describes:

- how the frequencies of harmonic partials can be calculated,
- how these calculations can be employed to generate simultaneous pairs of tones (dyads), and
- how the roughness of such simultaneous dyads can be measured and displayed.

In addition to the spreadsheet software Excel, which is employed for the frequency calculations and the resulting graphs and has been loaded onto Microsoft and Apple Macintosh computers by default, the other software employed below is currently downloadable online at no cost, namely:

- Audacity for audio generation: http://www.audacityteam.org/
- SRA 2.0 (Spectral and Roughness Analysis of Sound Signals) for roughness measurements: http://acousticslab.org/roughness/

The illustrations below are couched in terms of dyads that comprise one tone whose fundamental frequency is 300 cycles per second (i.e., 300 Hz) and a second tone whose fundamental frequency is expressed in terms of hundredths of a tempered semitone (i.e., cents) above or below 300 Hz.

Calculation of Frequencies

The number of Hz for each of the second tones' fundamental frequencies was calculated in an Excel spreadsheet by means of the following general formula:
=300*(2^(x/1200)).
In this formula, x is a value between -50 and 1250 (inclusive: $-50 \leq x \leq 1250$); this range corresponds to half a tempered semitone below 300 Hz to an octave plus half a tempered semitone above 300 Hz.
The formula 2^(x/1200) transforms, x, the number of cents (i.e., hundredths of a tempered semitone) below or above 300 Hz, into a number that when multiplied by 300 corresponds to the second tone's frequency (in Hz).

Between -50 cents and 1250 cents the values are calculated in increments of 10 cents:
-50, -40, -30, … 1230, 1240, 1250.
Accordingly, the 130 increments of 10 cents correspond to 131 intervals.

For each of the second tones, the value of its fundamental frequency (in Hz) is entered in a cell of the Excel spreadsheet.
Thereupon, the frequencies of the first five overtones above this tone's fundamental frequency are calculated in the Excel spreadsheet by means of the following general formula =x*y, where x is the number of Hz for the fundamental frequency, and y is a value between 2 and 6 (inclusive), namely, 2, 3, 4, 5, or 6.

The results of these calculations for all 131 dyads are entered in rows 10 to 15 of the Excel file ***Roughness measurements across an octave.xls*** which is accessible at ***xxx***

Generation of Audio Files

By means of Audacity freeware, each tone's fundamental frequency and 3-second duration is generated as follows, beginning with the tone whose fundamental frequency is 300 Hz:

- click on 'Tone…' in the 'Generate' menu

- select ‘Sine’ in the pull-down menu for ‘Waveform’
- enter 0.1 in the space for ‘Amplitude (0-1)’
- enter 00 h 00 m 03 s +00000 samples for ‘Duration’
- enter the fundamental frequency’s value in the cell for ‘Frequency (in Hz)’

Thereupon, each of the five overtones is generated as follows:

- in the ‘Tracks’ menu, click on ‘Add New’ and select ‘Audio Track’
- click on ‘Tone…’ in the ‘Generate’ menu
- select ‘Sine’ in the pull-down menu for ‘Waveform’
- confirm that 0.1 is still in the space for ‘Amplitude (0-1)’ and 00 h 00 m 03 s +00000 samples is still in the space for ‘Duration’
- enter the previously calculated frequency for the particular overtone in the cell for ‘Frequency (in Hz)’

When the sine tones for all six tracks have been generated,

- select all six tracks by clicking on ’Select’ in the ‘Edit’ menu and choosing ‘All.’
- click on ‘Mix and Render’ in the ‘Tracks’ menu.
- click on ‘Amplify…’ in the ‘Effects’ menu and enter -12 in the cell for ‘New Peak Amplitude (dB)’
- copy the tone that comprises the 300-Hz fundamental frequency and the five overtones above it (namely, 600, 900, 1200, 1500, and 1800 Hz) by clicking on ‘Copy’ in the ‘Edit’ menu

Generate the dyad’s second tone in the same way as described above.

Thereupon, for the dyad’s second tone,

- click on ‘Add New’ in the ‘Tracks’ menu
- select ‘Audio Track’ and
- paste into the added track the tone that comprises the 300-Hz fundamental frequency and its 5 overtones by selecting it and clicking on ‘Paste’ in the ‘Edit’ menu for the second tone

In the ‘Effects’ menu, click on ‘Amplitude…’ and enter -3 in the cell for ‘New Peak Amplitude (dB)’

Thereupon, click on ‘Zoom In’ in the ‘View’ menu so that one can see a mark for 0.05 seconds (i.e., 50 milliseconds) between the marks for ‘0.00’ and ‘0.10’
Move the cursor to this mark and select the region between this 0.05 mark and ‘0.00.’
In the ‘Effects’ menu, click ‘Fade In’
Then, select the region between the mark for 0.05 seconds and the end of the file at 3.00 seconds and click on ‘Fade Out’ in the ‘Effects’ menu.

Save the resulting audio file as a wav or aiff file by clicking on ‘Export…’ in the ‘File’ menu and selecting ‘WAV’ or ‘AIFF’ in the ‘Format’ menu and naming the file.

The audio file ***131 dyads with harmonic spectra.wav***, which is accessible at https://yorkspace.library.yorku.ca/xmlui/handle/10315/33029, contains all 131 dyads and can be opened in Audacity and saved by exporting it as a wav or aiff file.

Calculation and Display of Roughness Values

The freely accessible online software SRA 2.0 (Spectral and Roughness Analysis of Sound Signals), which is accessible at http://acousticslab.org/roughness/, was used to measure the roughness of the 131 dyads.
Among advantages of SRA are that its algorithm takes into account the effect of register and amplitude fluctuation (i.e., the relative amplitude values of interfering partials) on roughness.

Paste the following URL address into the browser: http://acousticslab.org/roughness/

Below the heading for section 1, 'File upload', click on the button 'Browse' and open the wav or aiff file.
In sections 2, 3, and 4, choose all the default values:

2) 'Frequency Analysis Resolution' 10 Hz
3) A. 'Spectral Amplitude Resolution' No
   B. Spectral Amplitude Threshold: leave blank for zero
4) A. leave blank
   B. 'Roughness Calculation', confirm that the default value is 'Every' 250 'milliseconds' and Click on the button 'Roughness Profile'

Copy the columns below the heading '11 pairs of time (milliseconds) and roughness values' and paste them into the Excel spreadsheet.
Delete the leftmost numbers (250, 500, 750, … 2750) within each cell.

In eleven rows of the Excel spreadsheet, align the eleven roughness values for each of the 131 intervals and select them all as a single group.
In the 'Insert' menu, click on 'Chart…' and click on 'Stacked Marked Line'

Along with a chart of the resulting measurements, the roughness values for all 131 dyads are entered in rows 18 to 28 of the Excel file ***Roughness measurements across an octave.xls***, which is accessible at https://yorkspace.library.yorku.ca/xmlui/handle/10315/33032