INTERNATIONAL ACOUSTICS RESEARCH ORGANIZATION

White Paper on the Harmonic Prominence Measure

Version 4 - March 2021

Document number IARO21-3

Preamble

The Harmonic Prominence (P_{harm}) measure has been constructed to quantify the prominence of low frequency harmonics of the kind emitted by artificial noise sources such as pumps or wind turbines, which may affect humans and animals through such mechanisms as the fight-or-flight response or entrainment. These will occur at frequencies close to those of a human, or animal, heartbeat.

The definition of prominence for this measure comes from the Matlab[1] function 'findpeaks,' which returns a list of peaks from (in this case) the 1/36th-octave, narrow-band-filter frequency spectrum of a sound file. The prominence of these peaks is defined as part of this function[2] and reproduced in the appendix.

Definition

The $\mathbf{P_{harm}}$ measure for a qualifying harmonic series is defined as the maximum prominence of all harmonic peaks (including the fundamental) between 0.5 Hz and 5 Hz.

The P_{harm} measure for a recording is the maximum P_{harm} measure of all qualifying harmonic series.

A **qualifying harmonic series** is a harmonic series within a 1/36th-octave, narrow-band-filter frequency spectrum in dBZ units.

Discussion

Prominence

Traditional measures relating to acoustics rely on the absolute value of sound pressure level (SPL) as they are more interested in such concepts as hearing thresholds and noise-induced hearing loss. When the focus switches to concepts such as annoyance, or 'special audible characteristics' it is the SPL above the background noise that becomes important, i.e., the prominence. This is because in human hearing, provided an acoustic feature is audible, it is the prominence that determines how clearly it can be distinguished.

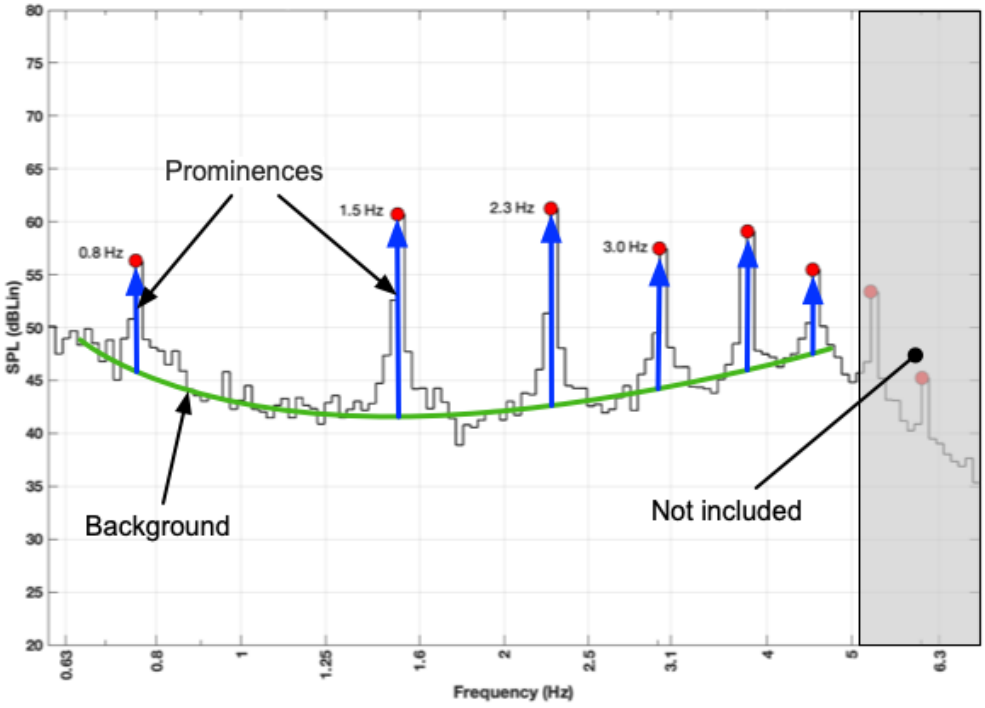

Figure 1: Prominence of a series of harmonic peak (blue) above the background (green).

Identifying the prominence above a background normally involves measuring the SPL when only the background is present and then when the feature of interest is present. The assumption that the background remains constant is invalid unless factors such as wind speed or rainfall can be accounted for.

When a narrow-band frequency spectrum (or Fourier transform) is taken of a sound signal, more traditional signal-processing techniques can be applied to find the prominence of specific frequencies above the rest of the 'background' frequencies. Such is the case with the 'findpeaks' function in Matlab. As shown in the Appendix, the method for determining the prominence of a peak is sophisticated and definite.

Fight-or-flight

The fight-or-flight response occurs when a stimulus is interpreted by the human or animal hindbrain as a threat. It causes a sudden release of cortisol that prepares the body

for instant and strenuous action. Repeated or prolonged triggering of this response can lead to a deterioration in the health of the organism.

Entrainment

Entrainment in the biological sense refers to the predilection of the body to synchronise some of its functions to an external rhythm. In particular, the heart rate can become synchronised with an external rhythm that is a reasonably close match or the harmonic of a reasonably close match.

Such entrainment has a negative effect upon the body and can lead to heart disorders.

Summation

When measures related to SPL are to be summed or averaged, the summation is normally performed on the energy of the measures. This is in accord with primary interest of acoustics on concepts such as hearing thresholds and noise induced hearing loss, which are related to the energy. In these it is the energy of the sound which creates the damage to the cochlea that causes the latter.

For all other matters the summation and averaging is customarily done using the deciBel scale as this relates to the perception of sound, i.e., that doublings of energy are perceived as linear increases in deciBel levels. Thus every increase of 6 dB doubles the energy but is perceived as an incremental increase in loudness.

Since the concept of prominence is most closely associated with perception, and many responses are due to perception, this is the approach taken here.

Note that the maximum deciBel level can also be relevant.

Frequency analysis

The magnitude of the prominences will vary with the width of the narrow-band filters used. Specifically, the height of the peaks will remain the same but the level of the background between them will fall as the width of the filters is reduced, below about 12th octave.

Between 1/36th-octave and 1/48th-octave filters, however, the largest prominences will increase by roughly 5%, with a similar difference in the P_{harm} measure (see the following two figures). The application of 1/36th-octave filters has been a standard for analysis by the IARO members for some years, since this bandwidth forms a suitable balance between adequate frequency resolution at higher frequencies and adequate temporal resolution at lower frequencies. The prominence analysis used for the P_{harm} measure is always performed on a spectrum created using 1/36th-octave filters.

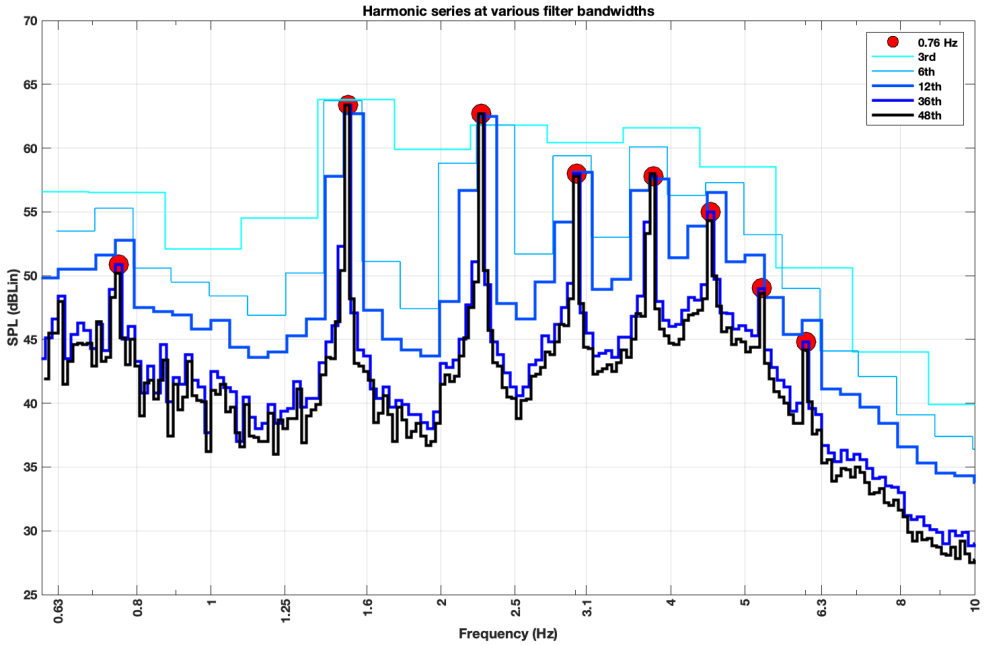

Figure 2: Harmonic series of peaks analysed with narrow-band filters of various widths.

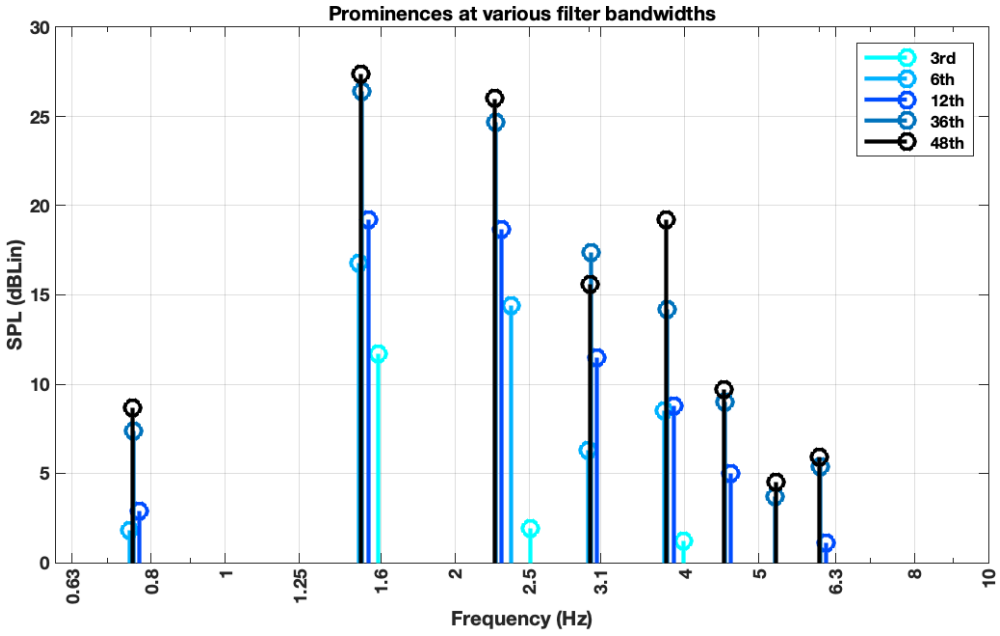

Figure 3: The measured size of the prominences in Figure 2 for various widths of narrow-band filters.

Implementation

Harmonic Prominence

The P_{harm} can be constructed from a recording by the following operations;

1. Construct a Class 0 filter bank of narrowband filters according to either ANSI® S1.11-2004 or IEC 61260:1995, with 1/36-octave bandwidths. The filter bank should extend from 0.5 Hz to at least 100 Hz.
2. The recording is filtered using the filter bank.
3. The filtered series are converted to an RMS average for each band over the length of the recording and then to deciBels to produce a frequency spectrum.
4. The peaks in the frequency spectrum are identified using the 'findpeaks' function in Matlab, returning the position of the peaks, their SPL values and their prominences. Only peaks more than 1 dB above the background are considered.
5. A harmonic analysis is carried out on these peaks to identify any harmonic series with fundamental frequency between 0.5 Hz and 5/3 (1.66) Hz. This is achieved by starting with a peak and seeking peaks at 2, 3, 4 etc times the frequency of the peak. The tolerance on the frequencies is slightly larger than the width of the narrow-band filter responsible, i.e., as the frequencies increase the tolerance becomes larger.
6. Harmonic series with fundamental frequencies that are exact multiples of any other harmonic series are eliminated.
7. Include any harmonic series that has a) one prominence greater than 3 dB and four or more peaks in the 0.5–5-Hertz range, or b) two prominences greater than 3 dB and three or more peaks in the 0.5–5-Hertz range.
8. The P_{harm} value for each qualifying harmonic series is the size of the largest the included prominences.
9. The maximum P_{harm} value from all the qualifying harmonic series is recorded as the P_{harm} for the recording.
10. For a specific noise source that has a harmonic series, P_{harm} is the P_{harm} value for that harmonic series. For instance, the P_{harm} for a wind turbine will be the P_{harm} of the harmonic series that has the blade-pass frequency as its fundamental frequency, referred to as the blade-pass P_{harm}.

The ACHE software suite can be used to create the P_{harm} using the output of its harmonic analysis. This stores the identified harmonic series, along with their prominences, in the /Derived/Data directory in files whose filenames end in "Harmonic Data - xxxx.csv," where "xxxx" is the name of the channel, usually "Blue" or "Red."

Harmonic Prominence Fundamental-Frequency Plots

Important harmonic series can be identified by plotting the P_{harm} of each 10-minute recording against its fundamental frequency as well as the frequency histogram of the fundamental frequency (i.e., how often it occurs). (See the following figure.)

The strong vertical lines in the top plot and the matching tall lines in the lower plot indicate those fundamental frequencies with a) large P_{harm} values and b) frequent occurrence. The discrete nature of the narrow-band filters can be seen in the upper plot and the twinned lines in both indicate that the fundamental frequencies varied slightly.

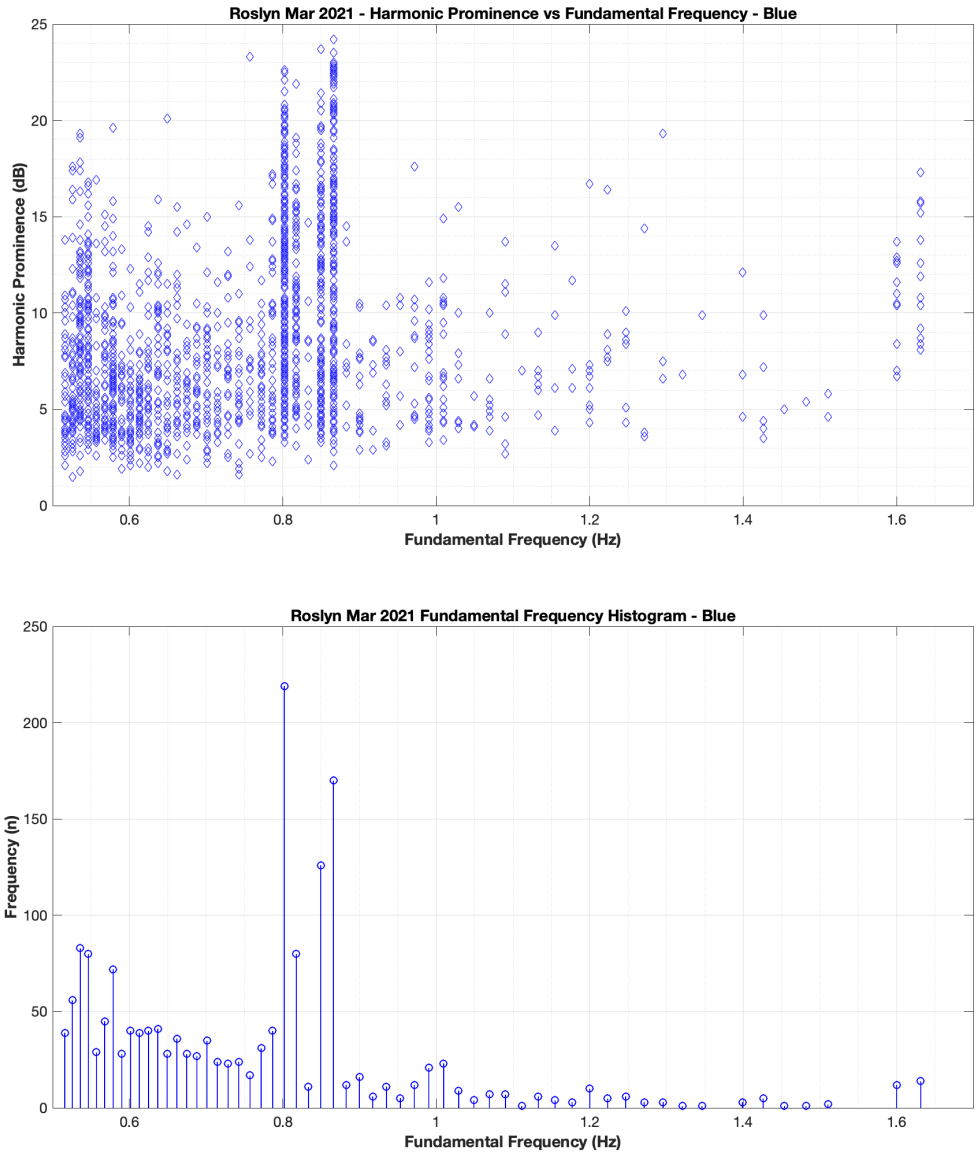

Figure 4: P_{harm} of multiple 10-minute recordings is plotted against the fundamental frequency of the P_{harm} harmonic series (top) and the frequency histogram of the fundamental frequencies (bottom).

By observation of the twin plots the two most important fundamental frequencies are seen to be roughly 0.8 Hz and 0.85 Hz. By taking an average of a sort over each of the twinned peaks, we can narrow down the fundamental frequencies to 0.81 and 0.86, respectively.

Harmonic Prominence Time-of-day plot

Plotting the harmonic prominence as a time-of-day vs day plot can reveal times of the day when prominences are particularly small or large. The following diagram is a P_{harm}

Time-of-day plot. Here each horizontal bar is the P_{harm} value of a 10-minute recording, the colour showing the value, as indicated by the legend on the right. Each vertical column is one day of the recording.

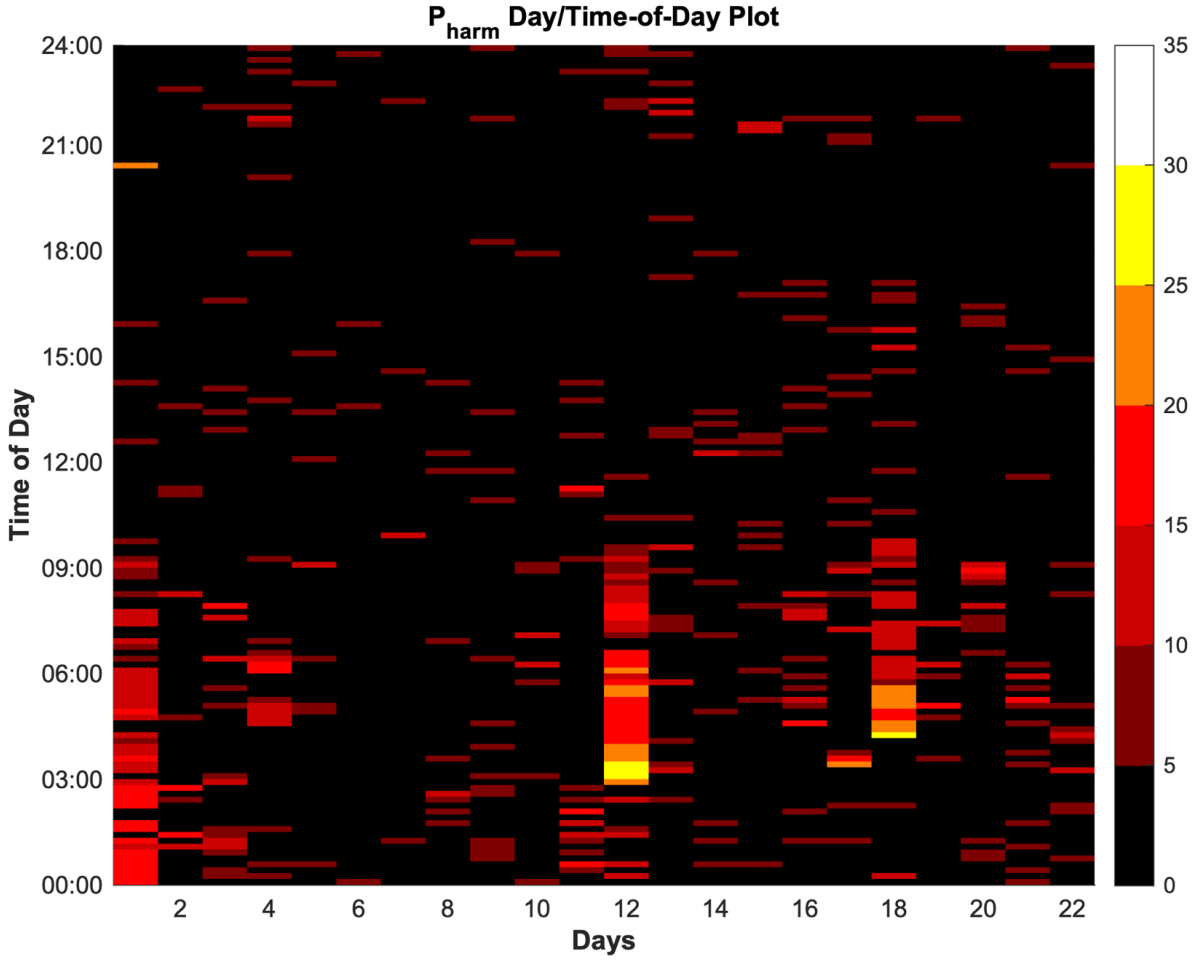

Figure 4: A harmonic prominence time-of-day plot with days horizontally, time of day vertically and the harmonic prominence value in colour according to the colour legend on the right.

Harmonic Prominence Wind Rose

The information contained in the P_{harm} from a number of successive recordings can be compactly represented on a prominence wind rose, analogous to a normal wind rose but representing the P_{harm} or $P_{harm\ eq}$. This can be constructed using the following operations;

1. Recordings are analysed to calculate their P_{harm} values. (These may be 'regularly spaced,' referring to the fact that, due to the onerous computational requirements of narrow-band filtering, it may be more effective to only process one or two 10-minute recordings per hour, usually the 0–10-minute and 30–40-minute recordings.)
2. Each of these values is matched with the concurrent wind speed and direction at the site or nearby weather station.
3. Bins are created for the combination of wind direction and P_{harm} level, e.g., bins for the wind direction in 5° increments and P_{harm} in 5-decibel increments.

4. The P_{harm} values are placed into their appropriate bins and tallied.
5. The prominence wind rose is then plotted as a stacked polar histogram where the axial direction denotes wind direction and the radial direction denotes the number of 10-minute recordings. Thus, the length of each 5-deciBel sector denotes the number of 10-minute recordings, while the colour denotes the P_{harm} level.

Such a wind rose is shown below.

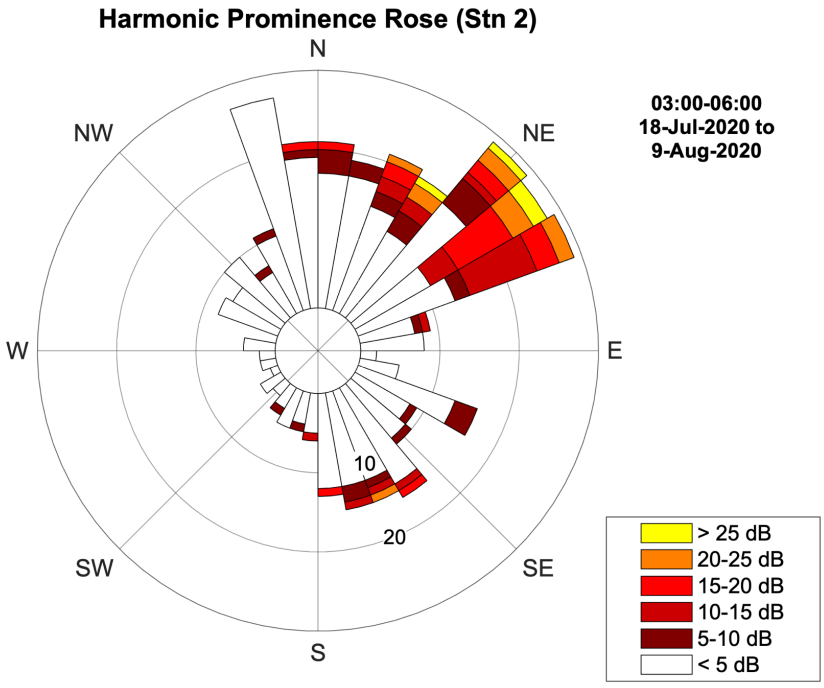

Figure 6: A harmonic prominence wind rose where the direction of a sector indicates the wind direction, the length of each section of the sector indicates the number of 10-minute intervals and the colour indicates the level of the harmonic prominence as shown in the legend.

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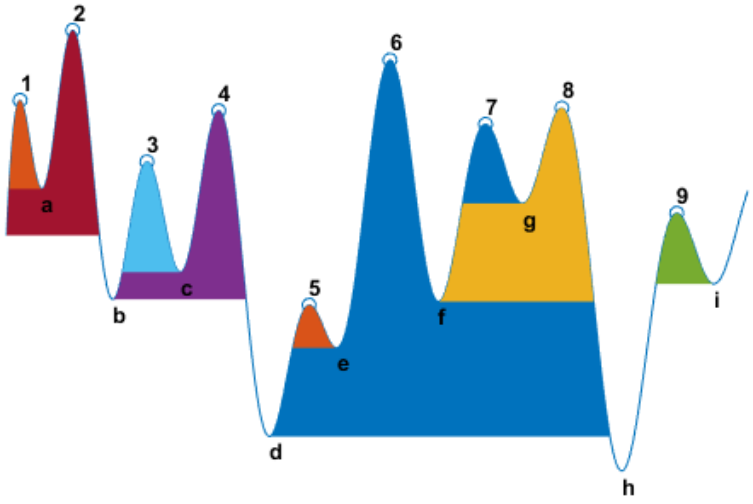
Appendix - Matlab prominence definition

Prominence

The *prominence* of a peak measures how much the peak stands out due to its intrinsic height and its location relative to other peaks. A low isolated peak can be more prominent than one that is higher but is an otherwise unremarkable member of a tall range.
To measure the prominence of a peak:

1. Place a marker on the peak.
2. Extend a horizontal line from the peak to the left and right until the line does one of the following:
   - Crosses the signal because there is a higher peak
   - Reaches the left or right end of the signal
3.
4. Find the minimum of the signal in each of the two intervals defined in Step 2. This point is either a valley or one of the signal endpoints.
5. The higher of the two interval minima specifies the reference level. The height of the peak above this level is its prominence.

`findpeaks` makes no assumption about the behavior of the signal beyond its endpoints, whatever their height. This is reflected in Steps 2 and 4 and often affects the value of the reference level. Consider for example the peaks of this signal:



Peak Number	Left Interval Lies Between Peak and	Right Interval Lies Between Peak and	Lowest Point on the Left Interval	Lowest Point on the Right Interval	Reference Level (Highest Minimum)
1	Left end	Crossing due to peak **2**	Left endpoint	**a**	**a**
2	Left end	Right end	Left endpoint	**h**	Left endpoint
3	Crossing due to peak **2**	Crossing due to peak **4**	**b**	**c**	**c**
4	Crossing due to peak **2**	Crossing due to peak **6**	**b**	**d**	**b**
5	Crossing due to peak **4**	Crossing due to peak **6**	**d**	**e**	**e**
6	Crossing due to peak **2**	Right end	**d**	**h**	**d**

7	Crossing due to peak **6**	Crossing due to peak **8**	**f**	**g**	**g**
8	Crossing due to peak **6**	Right end	**f**	**h**	**f**
9	Crossing due to peak **8**	Crossing due to right endpoint	**h**	**i**	**i**

[1] Matlab 9.7, The Mathworks Inc (Natick, MA, USA)

[2] Retrieved from https://au.mathworks.com/help/signal/ref/findpeaks.html?s_tid=srchtitle#bufbbs1-p, 18 Sept. 2020.