Envelope Rhythm Metrics

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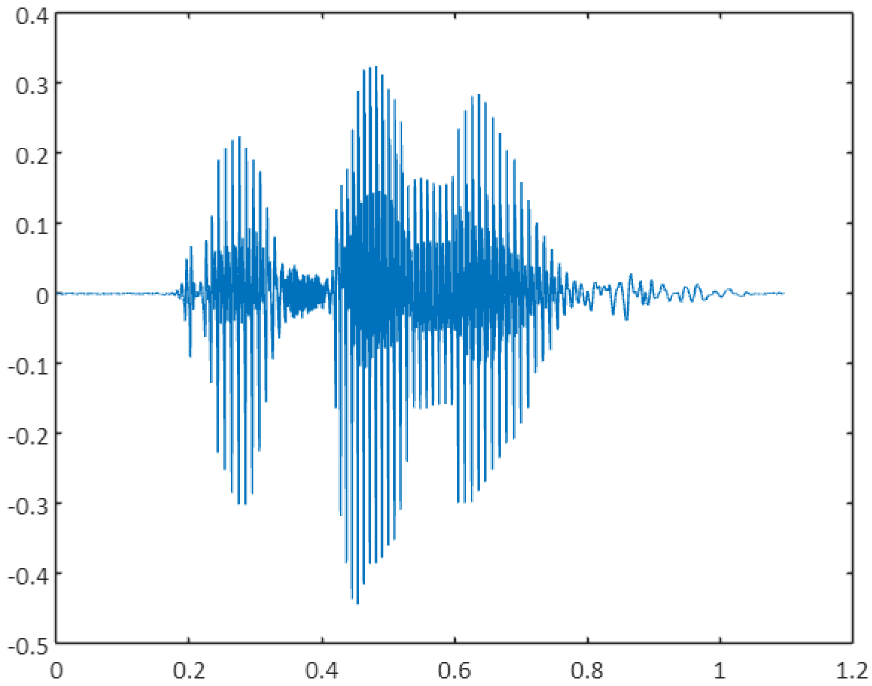
The vocalic energy amplitude envelope

Envelope rhythm metric analyses are usually applied to short chunks of speech (2-3 s).

```
%load example audio
addpath(genpath('.'));
file = ['.' filesep 'envmetrics' filesep 'example.wav'];
[x,wavFs] = audioread(file);
```

```
t = (0:length(x)-1)/Fs;
figls; plot(t,x)
```

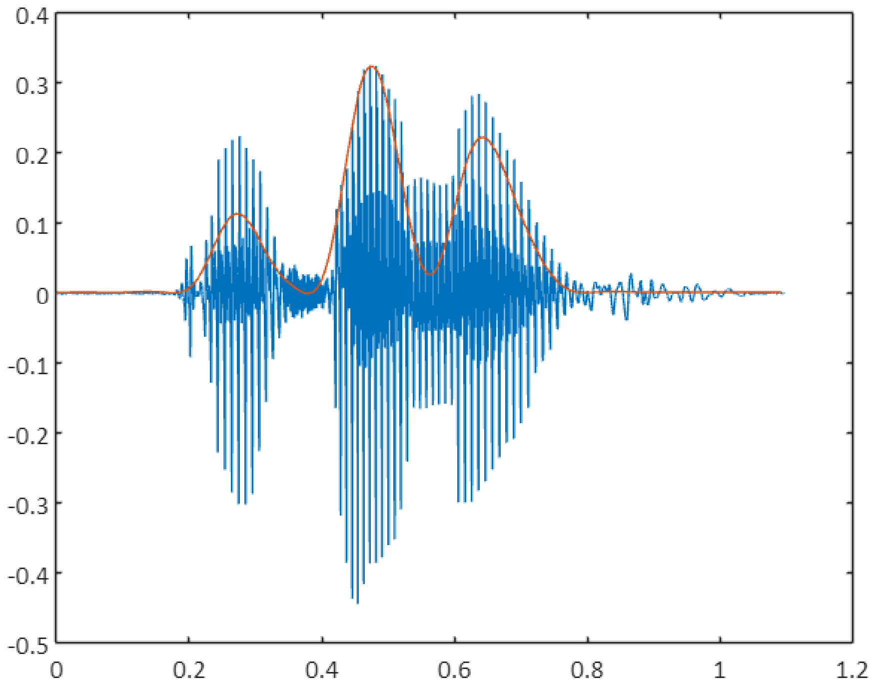


Extract envelope

```
par.bandpass = [400 4000];  %: vocalic energy bandpass range (there is no a priori justification for this range)
par.lowpass = 10;           %: lowpass filtering cutoff
par.Fs = wavFs;             %: sampling rate
par.ds = 100;               %: downsampling factor

%extract the envelope:
[env,t_env,x_bp] = envm_band_energy(x,par);
```

Plot envelope superimposed over waveform

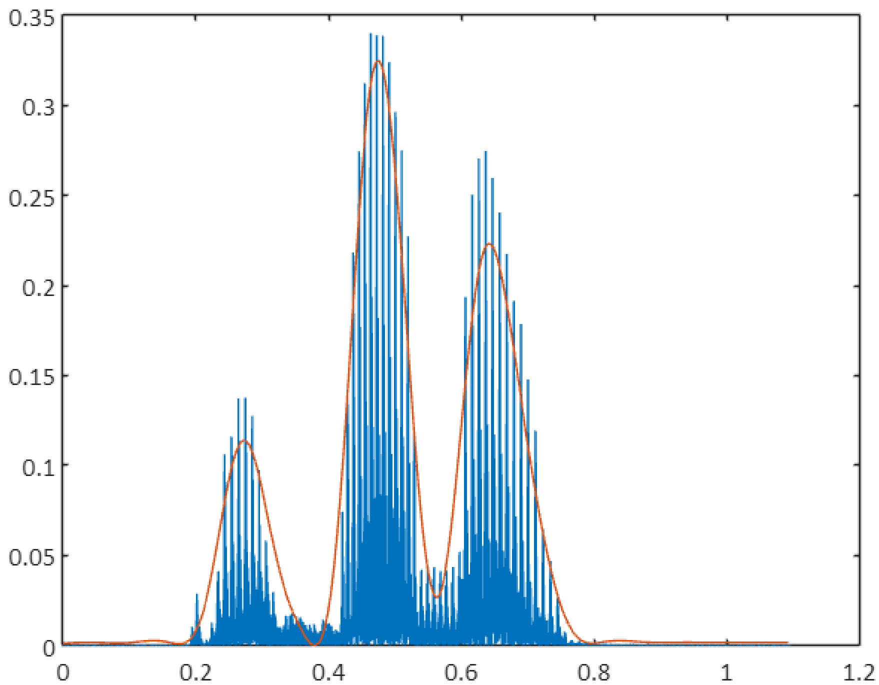
```
env = env-min(env);
env = env/max(env)*max(x);

figls; plot(t,x); hold on; plot(t_env,env);
```



The envelope is technically a "vocalic energy amplitude envelope", obtained from a low-pass zero-phase filtering of the absolute value of the band-pass filtered waveform. The vocalic energy band is defined in `par.bandpass.` For this reason, the envelope fits the magnitude of the vocalic energy waveform better than it fits the original signal.

Plot envelope superimposed over magnitude of vocalic energy waveform

```
figls; plot(t,abs(x_bp)); hold on; plot(t_env,env);
```



Low-frequency Fourier Analysis (LFFA)

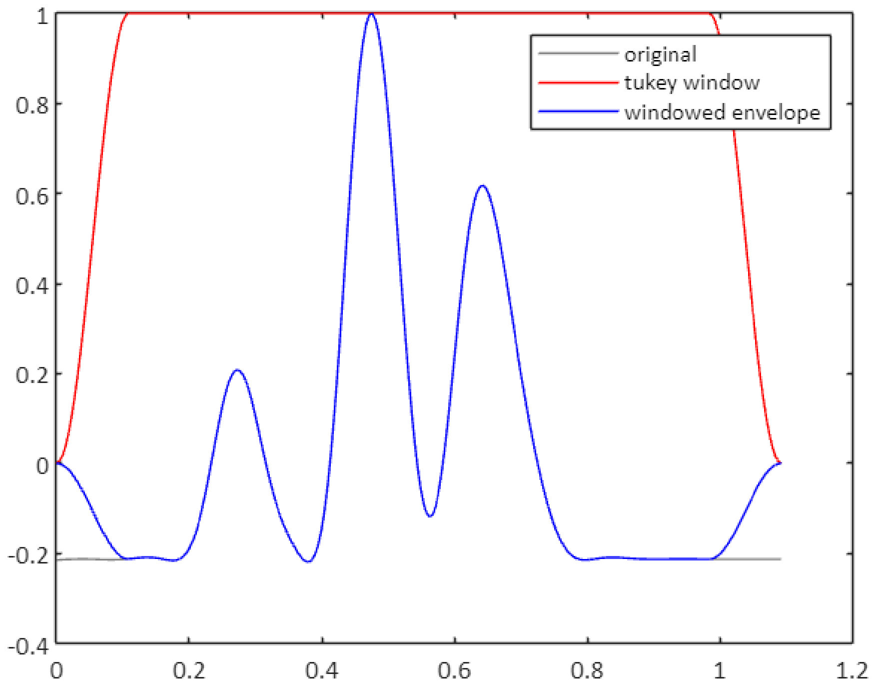
Pre-processing

First the envelope is zero-centered and rescaled:

```
env = env-mean(env);
env = env/max(abs(env));
```

The recentered envelope will generally be non-zero at its edges, so a tukey window is applied:

```
tw = tukeywin(length(env),0.2);
envw = env.*tw;
figls; plot(t_env,env,'color',[.5 .5 .5]); hold on; plot(t_env,tw,'r'); plot(t_env,envw,'b');
legend({'original','tukey window','windowed envelope'})
```

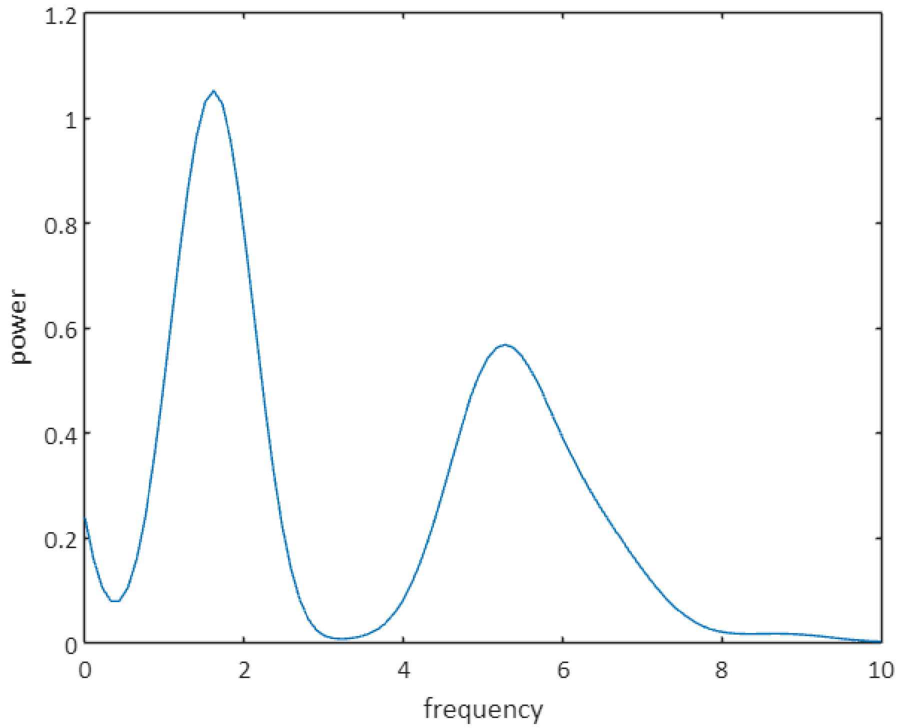


Smoothed power spectrum

```
%smoothed power spectrum
par.nfft = 2048;  %number of dft coefficients (should be > envelope length)
par.sm_Hz = 1; %smoothing bandwidth
par.Fs = wavFs/par.ds; %envelope sampling rate

[smpsd,f] = envm_smoothed_psd(envw,par);
```

Plot smoothed power spectrum

```
figls; plot(f,smpsd); hold on; xlim([0 par.lowpass]);
xlabel('frequency'); ylabel('power');
```



Obtain LFFA metrics

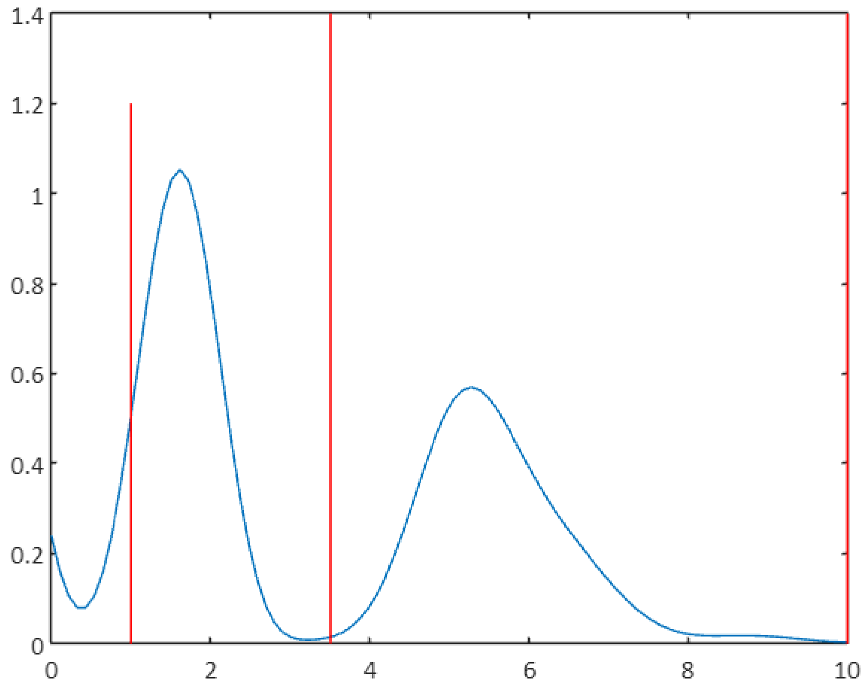
```
par.powerratio_freq_bins = [1 3.5 10];
par.centroid_freq_bins = [1 10];

LFFA = envm_psd_metrics(smpsd,f,par);
disp(LFFA)
```

```
     sbpr_1: 0.9817
    scntr_1: 3.6840
```

Spectral band power ratios

For each frequency band between the bin edges defined in `par.powerratio_freq_bins`, the `sbpr` is the ratio of power in the two bands.

```
figls; plot(f,smpsd); hold on; xlim([0 par.lowpass]);
for i=1:length(par.powerratio_freq_bins)
   plot(par.powerratio_freq_bins(i)*[1 1],ylim,'r-');
end
```

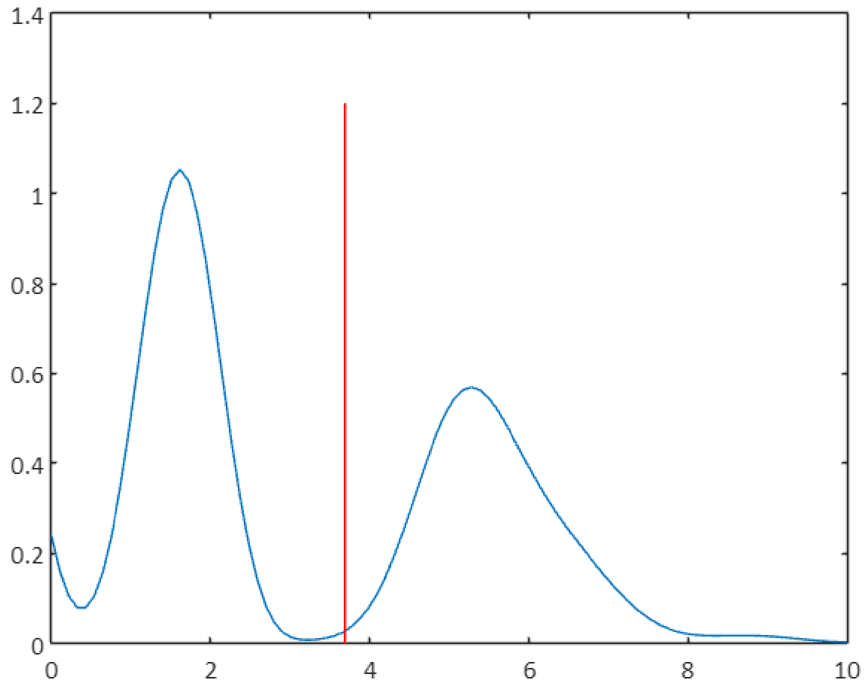



```
% Note that edges can be defined with three frequency values if the middle one is shared,
% e.g. this will give the ratio of power in the band [1,3.5] to power in the band [3.5, 10]:
par.powerratio_freq_bins = [1 3.5 10];

% or with four values if the bands are separated,
% e.g. this will give the ratio of power in the band [1,2] to the band [6,10]:
par.powerratio_freq_bins = [1 2 6 10];
```

Spectral center of gravity

The spectral center of gravity is centroid of the power in the frequency range specified in each row of `par.centroid_frequency_bins`:

```
figls; plot(f,smpsd); hold on; xlim([0 par.lowpass]);
plot(LFFA.scntr_1*[1 1],ylim,'r-');
```



Empirical mode decomposition metrics

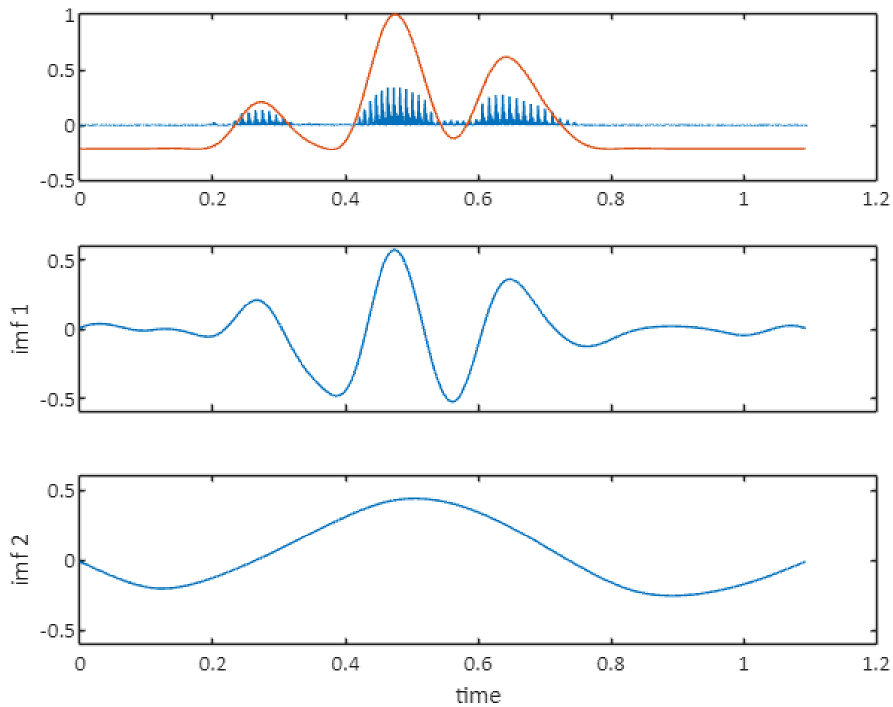
```
par.Fs = wavFs/par.ds; %envelope sampling rate

% empirical mode decomposition (EMD) / Hilbert-Huang transform (HHT)
% using a modified version of Alan Tan's toolbox:
% (http://www.mathworks.com/matlabcentral/fileexchange/19681-hilbert-huang-transform/content/
plot_hht.m)
[imf,w,t_imf] = envm_hht(envw,1/par.Fs);

%using matlab built-in functions (close but not quite identical to the toolbox):
% imf = emd(envw,'SiftRelativeTolerance',0.1,'MaxNumIMF',4);
% [hs,~,t_imf,w] = hht(imf,par.Fs);
% imf = num2cell(imf,1);
% w = num2cell(w,1);
```

Plot the intrinsic mode functions from EMD

The first IMF captures syllable-timescale oscillation, the second IMF captures stress-timescale oscillation. Higher-order IMFs can capture lower-frequency, phrase-timescale oscillations, especially for longer chunks.

```
figls;
Nimf = 2; %usually only the first two or three IMFs are analyzed
subplt = @(i)subplot(Nimf+1,1,i);
subplt(1); plot(t,abs(x_bp)); hold on; plot(t_env,env);
ax=[];
for i=1:Nimf
```

```
    ax(i) = subplt(i+1);  plot(t_env,imf{i});
    ylabel("imf " + i);
end
linkaxes(ax,'y'); set(ax(1:end-1),'XTicklabel',[]); xlabel('time')
```



Processing the instantaneous frequencies of the IMFs

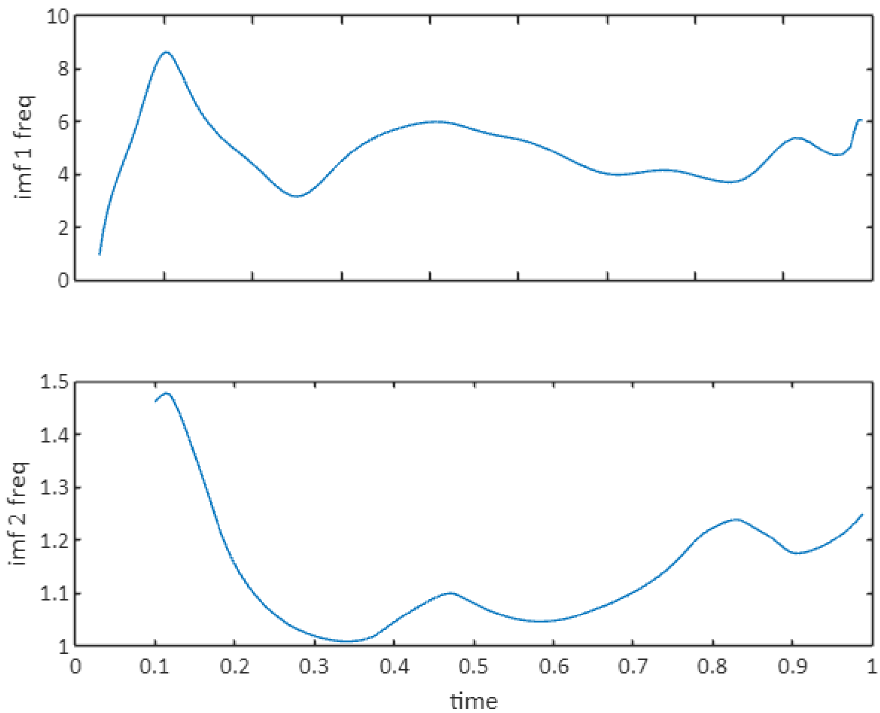
The frequencies are not meaningful where the IMF is not oscillating, so we remove edge values and values outside of expected ranges:

```
%Remove edge values:
edgedur = 0.1;
for i=1:length(w) %loop over chunks
      w{i}(1:round(par.Fs*edgedur)) = nan;
      w{i}(end-round(par.Fs*edgedur)+1:end) = nan;
end

%Remove out-of-range values
lower_bound = 0;
upper_bound = 13.16; %frequency at which magnitude response of 4th order butterworth is -10dB
for i=1:length(w) %loop over IMFs
    w{i}(w{i}<lower_bound) = nan;
    w{i}(w{i}>upper_bound) = nan;
end
```

Plotting the instantaneous frequencies

```
figls;
```

```
subplt = @(i)subplot(Nimf,1,i);
ax=[];
for i=1:Nimf
   ax(i) = subplt(i);  plot(t_imf(1:length(w{i})),w{i});
   ylabel("imf " + i + " freq");
end
set(ax(1:end-1),'XTicklabel',[]); xlabel('time');
```



Obtain EMD metrics

```
EMD = envm_emd_metrics(imf,w);
disp(EMD);
```

```
        pow_imf: [33.8030 47.9953 2.5518 0.1125]
           mu_w: [4.9155 1.1355 0.8696 0.2896]
          var_w: [1.4334 0.0120 0.0019 0.0015]
           sd_w: [1.1972 0.1096 0.0441 0.0388]
    imf_ratio21: 1.4199
```

IMF powers

These are the powers of the IMFs, defined as $\sum_t |\mathrm{imf}(t)|$

IMF average frequencies

The average instantaneous frequency of each IMF

IMF frequency standard deviations

The standard deviations of the instantaneous frequencies of each IMF, reflecting the stability of the rhythm on the corresponding timescale of the IMF

IMF power ratio

The ratio of power in the 2nd IMF (stress-timescale) to power in the 1st IMF (syllable-timescale)

Batch processing

The function `envm_metrics_batch` is designed to process a set of waveforms. It minimally requires a cell array of waveforms (which are usuallly chunks of speech) and a structure that specifies the sampling rate of the audio (which must be the same for all chunks), e.g.

```
files = "." + filesep + 'envmetrics' + filesep + ["example.wav"; "example2.wav"];
X={};
for i=1:length(files)
    [X{i},par.Fs] = audioread(files(i));
end

%uses default parameters:
METRICS = envm_metrics_batch(X,par);

disp(METRICS)
```

sbpr_1	scntr_1	imf_ratio21	pow_imf1	pow_imf2	pow_imf3	mu_w1	mu_w2	mu_w3	var_w1
1.0241	3.6274	1.5032	34.339	51.617	NaN	5.0428	1.1275	NaN	2.6562
1.2887	3.6527	0.88751	57.306	50.86	55.231	5.1716	2.3618	1.1298	8.6105

Parameters for batch processing

The following parameters can be specified:

```
disp(envm_default_params)
```

paramName	value	description
{'bandpass' }	{[400 NaN]}	{'bandpass filter edges. NaN = determine from sampling rate
{'lowpass' }	{[10]}	{'lowpass filter cutoff'
{'ds' }	{[100]}	{'downsampling factor'
{'tukeywin_param' }	{[0.1000]}	{'tukey window parameter for envelopes'
{'nfft' }	{[2048]}	{'number of dft coefficients'
{'sm_Hz' }	{[1]}	{'power spectrum smoothing bandwidth'
{'powerratio_freq_bins' }	{[1 3.5000 10]}	{'frequency bins for LFFA power ratios'
{'centroid_freq_bins' }	{[1 10]}	{'frequency range for LFFA centroid'
{'max_imf' }	{[3]}	{'maximum number of IMFs to return'
{'edge_null' }	{[0.1000]}	{'period of imf margins to ignore'
{'imf_freq_bounds' }	{[0 13.1600]}	{'allowed range of imf frequencies'
{'sift_relative_tol' }	{[0.1000]}	{'sift relative tolerance for Matlab built-in emd function
{'imf_freq_exclusion_prctile'}	{[99]}	{'percentile for exclusion of imf frequencies across datase
{'verbose' }	{[0]}	{'verbose output'

```
function [] = figls()
figure('Position',[0 0 640 480]);
end
```