

AMA: An Open-source Amplitude Modulation Analysis Toolkit for Signal Processing Applications

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Introduction

Typically, signal processing techniques assume (and require) the signals to be stationary. As stationarity is a strict assumption rarely present in naturally occurring signals, in practice, these signals are segmented into shorter time intervals where they are considered as stationary.

An interesting property of many naturally occurring signals is that the changes over time in their spectral content often occur in single or multiple periodic ways, resulting in cyclostationarity. Thus, these signals can be modeled as the interaction of two independent signals, a low-frequency signal that changes (i.e., modulates) the properties (such as amplitude, phase and/or frequency) of a higher-frequency signal. This interaction is the well known non-linear process of modulation.

Given the simplicity of its formulation, amplitude modulation (AM) modeling is often used and it has been shown to be an important tool for the analysis and synthesis of non-stationary processes in diverse fields such as telecommunications, speech and music perception, study of physiological signals such as the electrocardiogram (ECG), electroencephalogram and respiration.

Herein, we present the open-source amplitude modulation analysis (AMA) toolkit for MATLAB, Octave and Python. The toolkit provides functions to compute and visualize the transformations of multi-channel real-valued temporal signals into frequency, time-frequency, and modulation domain representations. The source code and examples are provided under the MIT licence.

The AMA toolkit is available at:
<https://github.com/MuSAELab>

Methods

For non-stationary signals, the Fourier transform (FT) does not provide information on the changes over time in the spectral content, thus a spectrotemporal representation is required to describe the dynamics of these signals. Common methods used to compute the spectrotemporal representation are the short-time Fourier transform (STFT), continuous wavelet transform (CWT), and the use of filterbanks together with the Hilbert transform (HT). The spectrotemporal representation, $X(t, f)$, obtained with these methods can be regarded as the result of the convolution between a time signal, $x(t)$, and a complex oscillatory function, $e^{j2\pi ft}$, which is tapered by the real-valued time window function $\lambda_f(t)$, i.e.:

$$X(t, f) = x(t) \star \lambda_f(t) e^{j2\pi ft}$$

While this spectrotemporal representation describes the temporal behaviour of the spectral components that conform the non-stationary signal, it does not characterize their periodic behaviour. Thus, a natural extension of the spectrotemporal representation is the modulation spectrogram, which characterizes those temporal changes in the magnitude of the spectrotemporal representation.

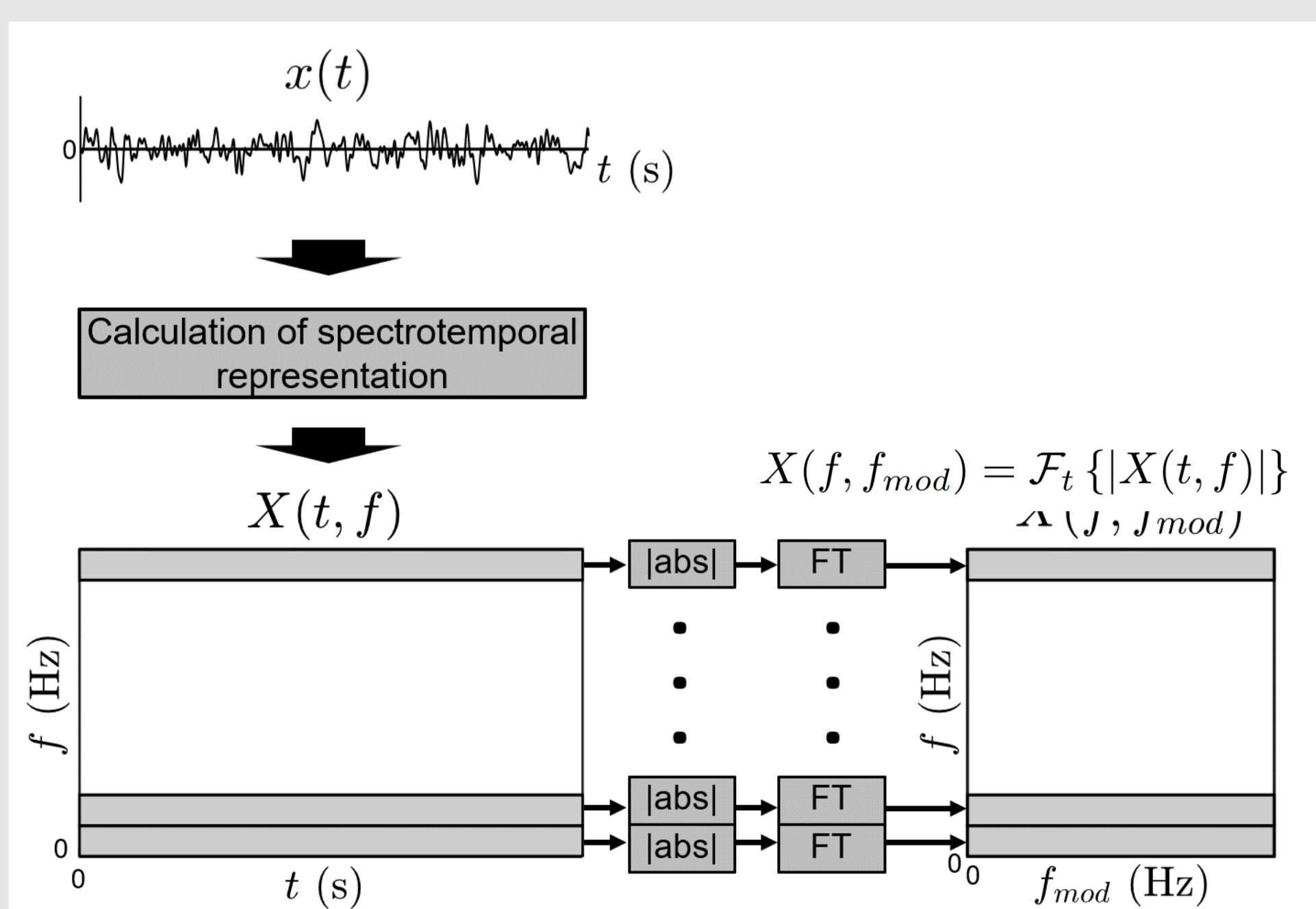


Figure 1. Signal processing steps for the modulation spectrogram calculation.

Toolkit description

The AMA toolkit provides the functions to compute forward and inverse transformations between time, frequency, time-frequency, and frequency-modulation-frequency domains for real-valued signals.

Table 1. List of functions included in the AMA toolkit

Time ↔ Frequency	
<code>rfft()</code>	FFT of a real-valued signal
<code>irfft()</code>	Inverse FFT of real-valued signal
<code>rfft_psd()</code>	FFT-based PSD
<code>irfft_psd()</code>	Inverse of FFT-based PSD
Time ↔ Time-frequency	
<code>strfft_spectrogram()</code>	STFFT-based spectrogram
<code>wavelet_spectrogram()</code>	CWT-based spectrogram
<code>istrfft_spectrogram()</code>	Inverse of STFFT-based spectrogram
<code>iwavelet_spectrogram()</code>	Inverse of CWT-based spectrogram
Time ↔ Modulation	
<code>strfft_modulation_spectrogram()</code>	STFFT-based modulation spectrogram
<code>wavelet_modulation_spectrogram()</code>	CWT-based modulation spectrogram
<code>istrfft_modulation_spectrogram()</code>	Inverse of STFFT-based modulation spectrogram
<code>iwavelet_modulation_spectrogram()</code>	Inverse of CWT-based modulation spectrogram

A graphical user interface (GUI) is provided as an interactive tool for the real-time exploration of signals and their representation in different domains. Finally, examples of the use of the AMA toolkit are also provided.

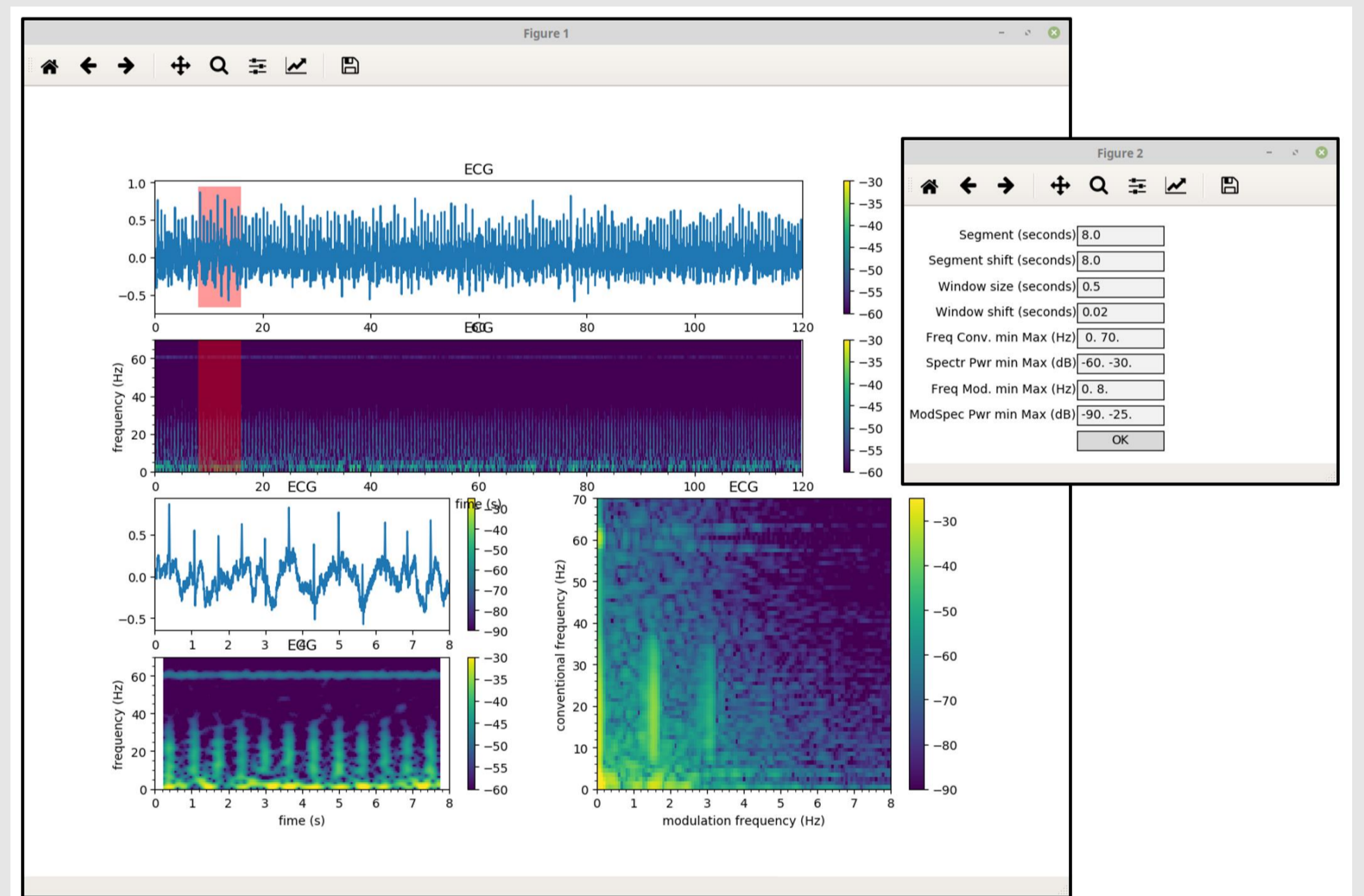


Figure 2. GUI of the Amplitude Modulation Analysis toolkit.

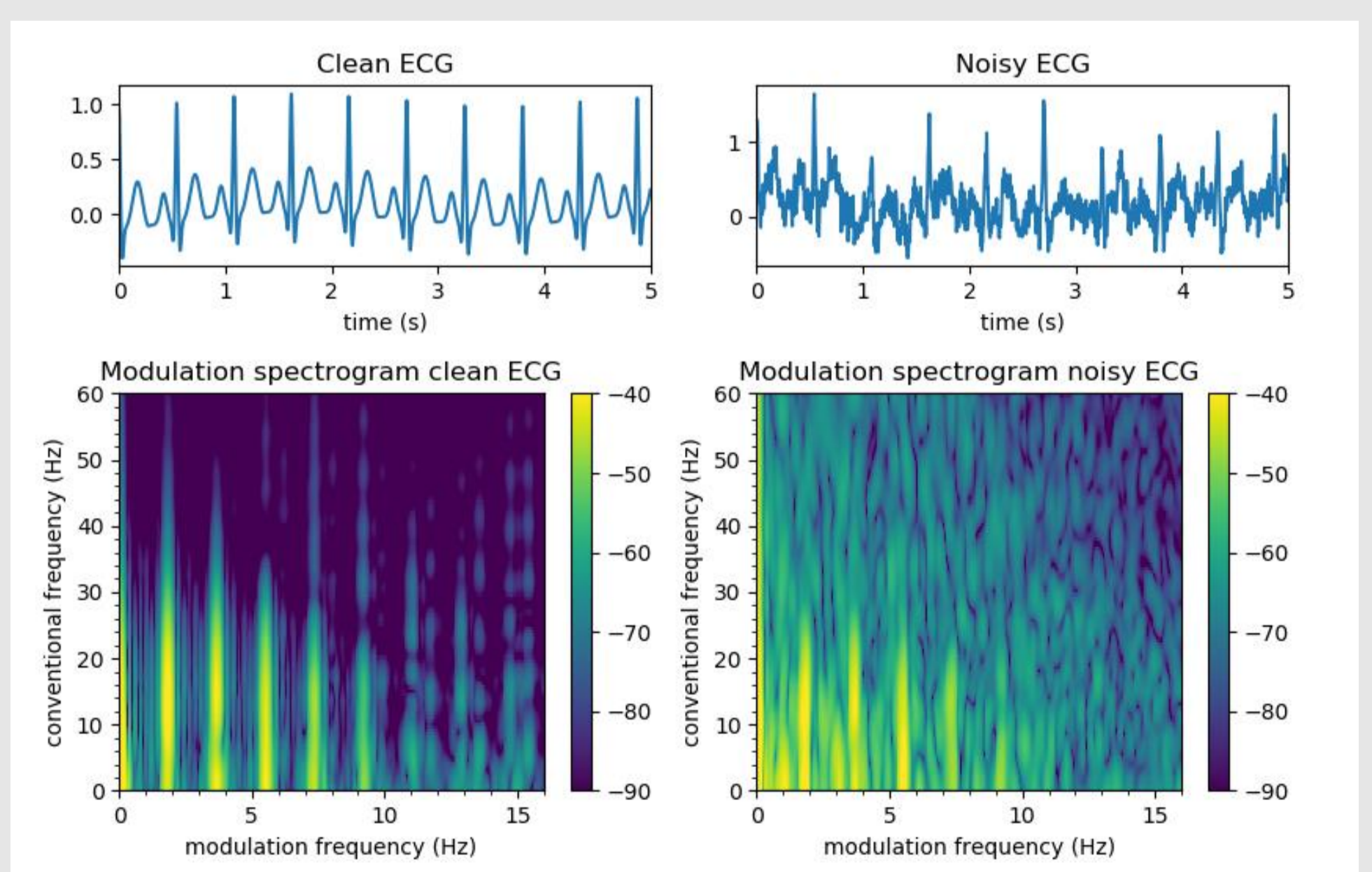


Figure 3. Example of the use of the AMA toolkit to analyze ECG data

Conclusion

The AMA toolkit has been developed to be an out-of-the-box solution for researchers to facilitate them the use of the amplitude modulation approach for the study, analysis, synthesis and understanding of signals across a wide range of domains.

References

- [1] R. Cassani and T. H. Falk, "Spectrotemporal Modeling of Biomedical Signals: Theoretical Foundation and Applications," in Reference Module in Biomedical Sciences. Elsevier, 2018.
- [2] D. P. Tobon V., T. H. Falk, and M. Maier, "MS-QI: A Modulation Spectrum-Based ECG Quality Index for Telehealth Applications," IEEE Transactions on Biomedical Engineering, vol. 63, no. 8, pp. 1613–1622, Aug. 2016.