A brief introduction to the Frequency Amplitude Variation (FAV) and Modified FAV methods used in vessel noise detection.

Introduction

Vessels generate sound emissions characterized by a combination of broadband and stationary narrow-band signals, typically exhibiting peaks below 1 kHz. The broadband components are primarily produced by the propeller cavitation process and can be detected using a class of methods based on the DEMON principle. However, DEMON methods often perform poor in noisy environments [1]. Another limitation of DEMON-based algorithms is their dependence on band-pass filter selection by operators to target specific vessel types. To overcome these issues, Reis et al. (2019) introduced the frequency amplitude variation (FAV) noise detection technique, which focuses on the narrow-band components of vessel noise, resulting in a more robust approach. FAV has been tested on underwater sound recordings from two conservation areas in São Paulo, Brazil, and has demonstrated superior performance in noisy conditions compared to existing solutions [1]. However, the FAV algorithm is only effective in detecting large vessels (e.g., tankers) with constant acceleration, as their noise manifest themselves as continuous, narrow tonal bands on spectrograms. In contrast, small-engine boats often exhibit erratic acceleration patterns that result in modulating tonal nose, thus wider peaks (compared to the ship related peaks) in representative frequency spectrum plots. To tackle the latter challenge, a modified version of the FAV method is proposed and tested on several databases, with success in detecting boat noise as well.

Frequency Amplitude Variation (FAV) method

The Frequency Amplitude Variation (FAV) algorithm is designed to detect vessel sounds by identifying amplitude peaks in the frequency spectra of sound recordings [1]. The FAV algorithm leverages the stationary narrow frequency signature of emitted vessel-noise on spectrograms. The vessel noise detection process begins by reading an underwater acoustic signal and generating its corresponding spectrogram (i.e. the time-frequency representation), using Short-Time Fourier Transform (STFT) algorithm. The spectrogram is then divided into several time segments, as demonstrated in Figure 1. Each time segment is averaged along the time axis and moderately smoothed using a Blackman window filter to generate the representative frequency spectrum of each time segment, as shown by the black curve in Figure 1. The averaging process enhances the vessel-noise-signal to background-noise (as the persistent vessel-noise in time adds up constructively while the random background noise cancel out each other). Subsequently, the differences between consecutive frequency bins of the smoothed spectrum are raised to the power of three (a value determined through trial and error), resulting in the curve depicted in Figure 2-a. The differencing step act as a de-trending process and only high frequency variations in the frequency spectrum remain, that are further amplified by raising to the power of three. The next step involves applying a transformation to the difference curve by multiplying its shifted negative counterpart, generating only positive peaks as shown in Figure 2-b. Eliminating the negative peaks facilitates the application of the following automated peak selection algorithm. At this stage, a threshold is introduced to exclude values below a certain threshold, which is 1.5 times the square of standard deviation of the smoothed spectrum, suggested by Reis et al. (2019), but may be fine-tuned, as appropriate. A peak selection algorithm is then applied to the resulting plot (Figure 2-c) to pick ship associated noise peaks. This methodology can be iteratively applied across different frequency bands, as required.

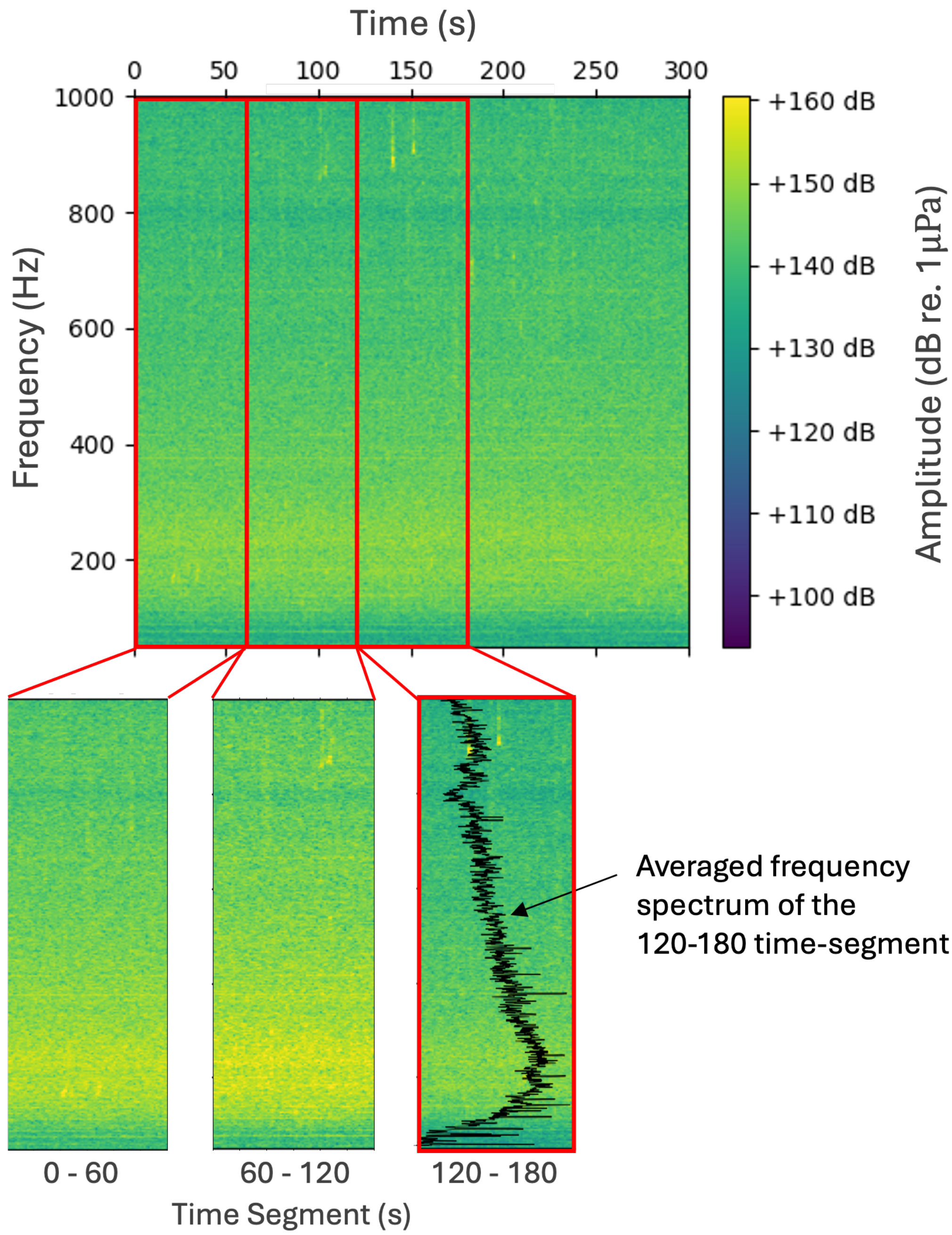

Figure 1: Spectrogram representation of a five-minute hydrophone signal over frequency band of 0-1000 Hz, segmented to 60-second time windows. The black curve represents averaged frequency spectrum of the 120-180s time segment.

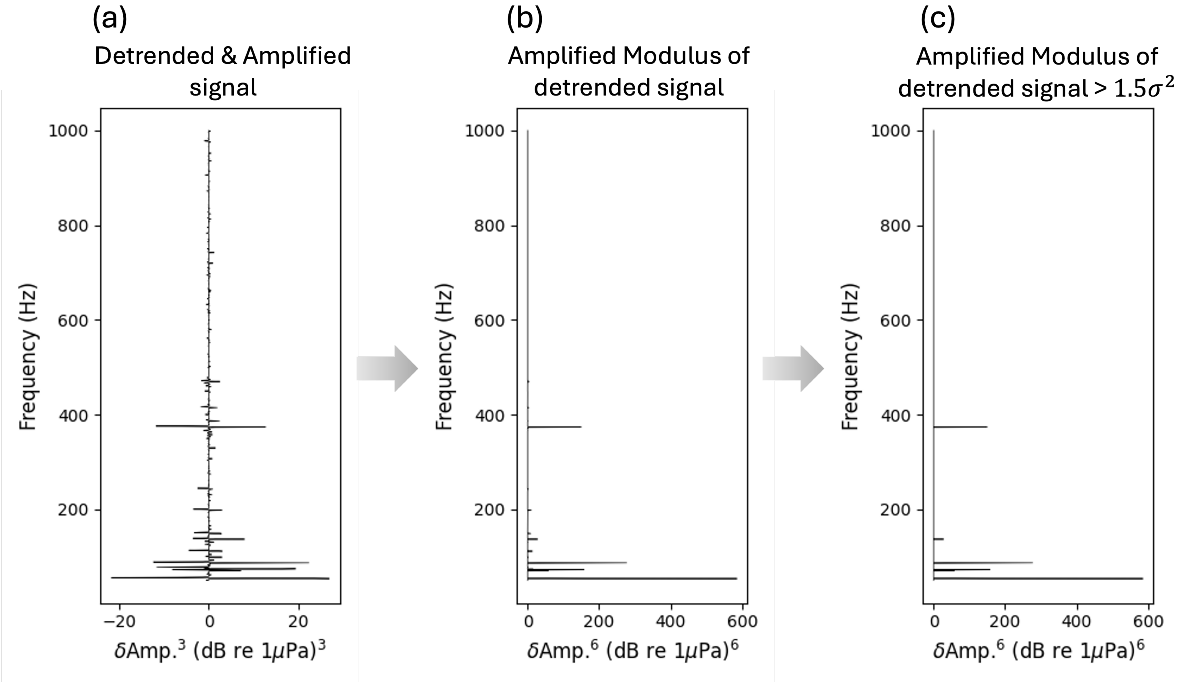

Figure 2: Schematic illustration of the FAV method used to detect vessels' noise signals. Panel (a) shows the de-trended and amplified plot of the averaged spectrum (the black curve in Figure 1), obtained by raising the frequency differences over consecutive bins to the power of 3. Panel (b) shows the result of de-trended signal multiplied by its shifted negative counterpart. Panel (c) shows filtered version of the curve in panel b, obtained by accepting only the values greater than 1.5 times the squared standard deviation of the averaged spectrum.

Modified Frequency Amplitude Variation (MFAV) method

The modified version of FAV (MFAV) method builds upon the basic principles of FAV, but adopting an alternative approach for de-trending averaged frequency spectrum and identifying vessel noise peaks from the high-frequency components. Once the smoothed average frequency spectrum of a time segment is obtained (Figure 3-a), a high-pass frequency filter is applied to retain the high-frequency components of the spectrum (Figure 3-b). This approach offers greater flexibility in preserving broader tonal noise imprints on frequency spectra for further analysis. It is particularly useful when detecting small-engine noise on a spectrogram, which, due to its modulating character, appears as wider peaks on averaged frequency spectra, in contrast to the narrower peaks associated with large vessel noise. Next, the high-pass filtered frequency spectrum is normalized by a factor of 3.5 (or a larger value) times its standard deviation. The assumption here is that the high-frequency components represent random ambient noise and follow a normal distribution. High-frequency components with normalized values greater than one can be attributed to vessel noise. The amplitudes of those frequency peaks that exceed the 3.5 standard deviation threshold are greater than the amplitudes of 99.93 percent of the high-pass filtered spectrum components, and can thus be considered outliers, potentially representing vessel noise (Figure 3-c). This peak detection approach provides a logical framework within the statistical context for detecting those vessel noise signals that exceed a certain threshold above the background sound pressure level.

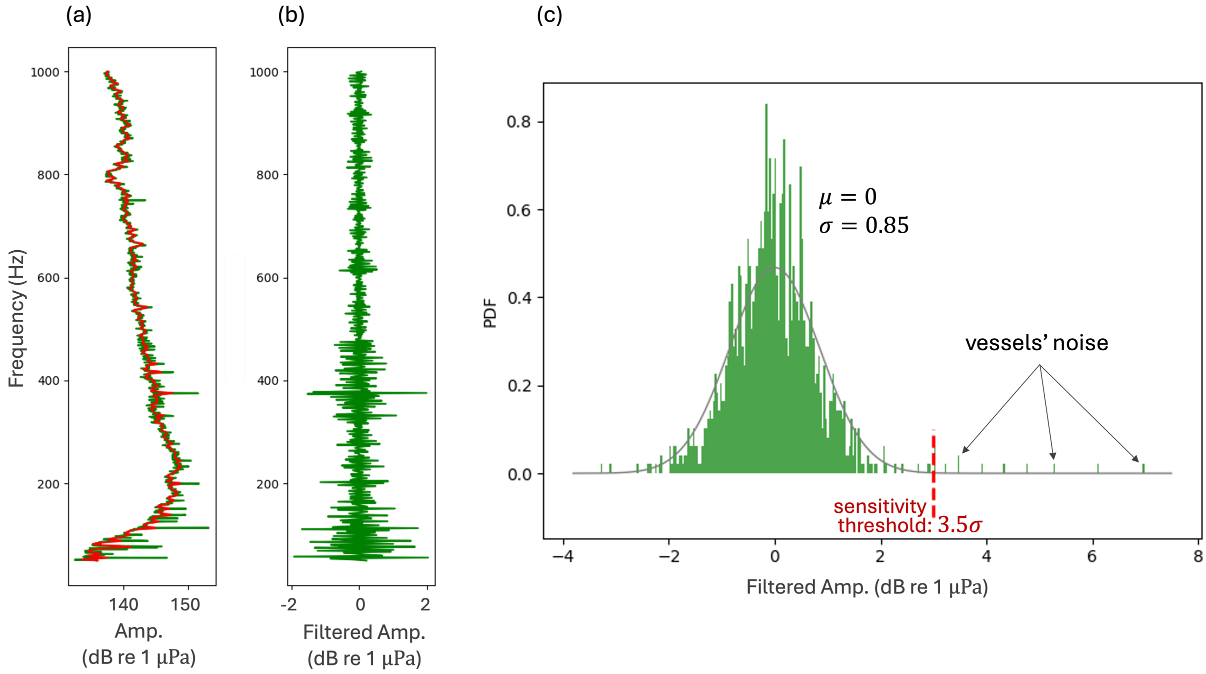

Figure 3: Schematic illustration of the FAV^{mod} method as an alternative to the FAV approach. Panel (a) shows the averaged spectrum of the 120-180 time segment (green curve) overlain by the low-pass filtered spectrum (red curve), with a cutoff frequency of 5000 Hz. Panel (b) shows the filtered frequency spectrum after the application of a 5000 Hz high-pass filter to the averaged spectrum. Panel (c) demonstrates the histogram plot of the high-pass filtered spectrum displayed in panel (b). The green lines show the data, and the grey curve represents the normal distribution fit to the data. The parameters μ and σ represent the mean and standard deviation of the data, respectively. The 3.5σ threshold used to define the vessel noise outliers is shown by the red dashed line.

References

[1] Clausius D. G. Reis, Linilson Rodrigues Padovese, and Maria C. F. de Oliveira. Automatic detection of vessel signatures in audio recordings with spectral amplitude variation signature. *Methods in Ecology and Evolution*, 10(9):1501–1516, 2019.