DYNAMIC NORMALIZATION OF HYDROACOUSTIC SIGNALS

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Multidimensional analysis of hydroacoustic data is usually conducted by way of presentation of the signal information decomposed into dimensions of time and frequency using a short term Fourier transform in form of a spectrogram. Some shortfalls of such visual analysis come into place when studying a signal coming from a source changing its distance from the receiver set because of the variations in the signal strength. The proposed method suggests some ways of such normalization scheme that will diminish the influence of these variations by way multiplication of the spectra by a compensation function dependent of time.

INTRODUCTION

Fast Fourier transform has been long used in hydroacoustics as an excellent tool for showing a frequency content of a stationary signal. It is also quite obvious that applying FFT to the time domain data is equivalent to a transformation of such data into the frequency domain and creation of sound spectra. Such numerical operation is done in order to significantly improve the ability to investigate the temporary characteristics of a sound signal and facilitate further signal analysis. One of the more prominent application of digital signal processing theory and especially the determination of spectra is to investigate the temporary physical state of an object being the unique source of a given sound signal. However, if our objective is the study not of a momentary sound source state at any given moment but the complex change of the time dependent sound source condition singular spectra may not always be sufficient for such analysis. Such is the case when we want to study a state of ship as a complex underwater non-stationary sound source. Investigations carried out *in-situ* at a coastal zone measuring range had shown that the overall sound pressure level of a ship signature changes in time as a function of the distance of a sound source or a ship from a fixed hydrophone (figure 1). While the object is approaching and the distance is diminishing the sound pressure is increasing reaching its peak at the so called closest point of approach after which the situation is reversed for the sound pressure level to gradually grow smaller (figure 1).

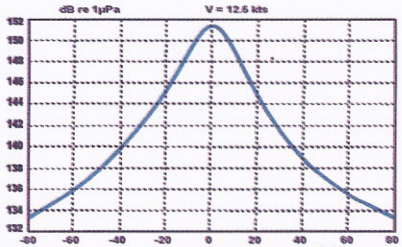

Fig.1. Sound pressure of a moving vessel in respect to her distance from a hydrophone

The consequence of this process is that consecutive sound signal spectra obtained at different locations demonstrate correspondingly changing frequency amplitude shifts. The goal of this article was not to look into the mechanics of such shifts, which obviously is a complicated phenomenon having to do with the degradation of sound signal propagating through a complex environment but rather to answer the question what can be done to the consecutive spectra (in function of time) in order to bring them all to a "common denominator" so that it would improve the ability to:

- study visually the sound spectra in respect to time;
- facilitate the spectral data for neural object classification methods.

Existing equipment used for sound signal analysis such as a programmable signal analyzer GC-89 are not equipped with the ability for dynamic signal amplitude compensation for their three dimensional presentations. In GC-89 it is possible to apply an amplification function for the whole time range of a signal equally, which is understandable from the typical user perspective when it is most important to represent the amplitudes of a signal equivalent to the real signal that is measured by a hydrophone. The further investigation is therefore based upon two assumptions: a) within our scope of interest are only underwater acoustic signatures of moving vessels, b) the corrected spectrograms will be used for the purpose of artificial neural network purposes (eg. object classification, motion parameters identification).

1.SPECTROGRAM COMPENSATION FUNCTION

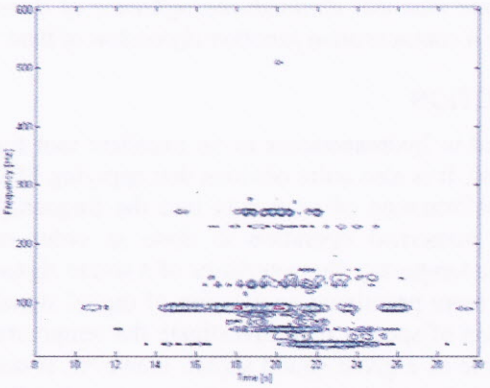

Fig.2. Typical spectrogram for a vessel approaching a hydrophone

Because the acoustic signature of a moving vessel is a non-stationary signal it is usually represented by means of a spectrogram. A typical representation is shown on figure 2. It can be clearly seen that for the signal presented above the average amplitude levels for consecutive spectra change gradually with time and at time t=21s achieve their highest values which corresponds to the moment at which the investigated object was located at the closest range from the measuring set. This is obviously consistent with the general sound pressure diagram presented in figure 1. As the goal of this paper was to create such kind of compensation for the spectra so that they are raised to a comparable level (especially for purpose of artificial neural analysis of a signal) it would be helpful to demonstrate numerically how a spectrogram is created. *Spectrogram* is equivalent to the short time discrete Fourier transform, STDFT. There is only a minor difference between STFT and FT. In STFT, the signal is divided into small enough segments, where these segments (portions) of the signal can be assumed to be stationary. For this purpose, a window function **"w"** is chosen. The width of this window must be equal to the segment of the signal where its "stationarity" is valid.

This window function is first located to the very beginning of the signal. That is, the window function is located at t=0. Let's suppose that the width of the window is **"T"** s. At this time instant (t=0), the window function will overlap with the first **T/2** seconds (I will assume that all time units are in seconds). The window function and the signal are then multiplied. By doing this, only the first T/2 seconds of the signal is being chosen, with the appropriate weighting of the window (if the window is a rectangle, with amplitude "1", then the product will be equal to the signal). Then this product is assumed to be just another signal, whose FT is to be taken. In other words, FT of this product is taken, just as taking the FT of any signal.

The next step would be shifting this window (for some t1 seconds) to a new location, multiplying with the signal, and taking the FT of the product. This procedure is followed until the end of the signal is reached by shifting the window with "t1" seconds intervals. The creation of the short time Fourier transform may be represented by the following formula for STFT of signal x(t) computed for each window centered at (t- τ):

$$STFT_x^{\omega}(\tau,\omega)=\int\left[x(t)\bullet W(t-\tau)\right]\bullet e^{-j\omega t}\,dt \tag{1}$$

where: . – time parameter, . – frequency parameter, **x(t)** is the signal itself, **W(t-τ)** is the window function centered at t- τ**.**

The proposed method for signal compensation described above involves introducing a new function ß(.), which will be different for each location of time windows, that will be multiplied by all components in each spectrum. Such an operation will not deform any single spectrum but will only change an overall appearance of a new spectrogram and make it more suitable for visual analysis and for further neural network processing. The new formula for short time FT will look therefore as follows:

$$STFT_x^{\omega}(\tau,\omega)=\beta(\tau)\bullet\int_t\left[x(t)\bullet W(t-\tau)\right]\bullet e^{-j\omega t}\,dt \tag{2}$$

One way to choose the compensation parameter ß(.) is to be the inverse of the maximum frequency amplitude for a spectrum located at time .:

$$\beta(\tau) = 1/\left(\mathrm{Max}\left[STFT_x^{\omega}(\tau,\omega_0\ldots\omega_{\max})\right]\right) \tag{3}$$

The change in the resulting spectrogram is shown on the following figure:

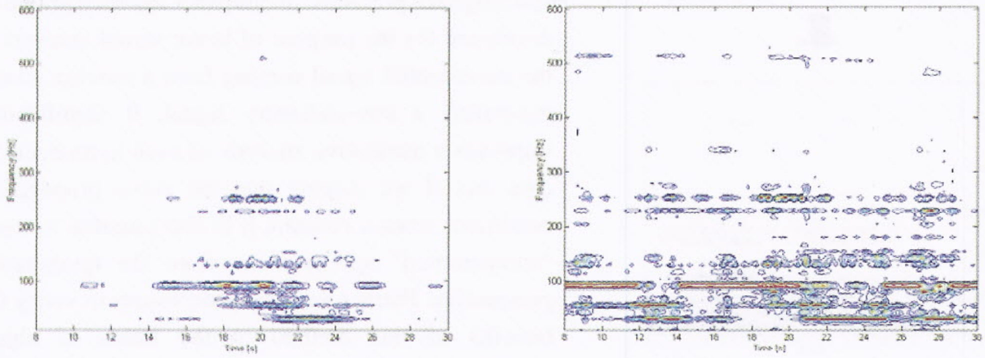

Fig.3. Application of the compensation parameter ß(τ) to the (contour) spectrogram of a moving ship

It is visible from figure 3 that such modification of the short time Fourier transform greatly improved the amount of information presented in the spectrogram by increasing the frequency resolution of the analysis. By analyzing formula (3) it may be deduced that in the resulting spectrogram the low amplitude components in all spectra are now elevated to the level of the components in the spectrum the highest energy content.

There are other possibilities for determination of the ß(.) function. In the following example this function is obtained by using the Nth order polynomial approximation of the effective value of the given ship's acoustic pressure at a hydrophone. The polynomial function is then reversed and normalized to the range <1 A>, where A signifies the amplification of the compensation process. Therefore:

$$\beta(\tau) = A\,(\mathrm{Max}[P_C^N(\tau_0 \ldots \tau_{\max})] - P_C^N(\tau)\,)\,/\,(\mathrm{Max}[P_C^N(\tau_0 \ldots \tau_{\max})] - \mathrm{Min}[P_C^N(\tau_0 \ldots \tau_{\max})]) + 1 \qquad (4)$$

where, $P_C^N(\tau)$ - is the N^{th} order polynomial approximation of the effective value of the given ship's acoustic pressure at time t, $\mathrm{Max}[P_C^N(\tau_0 \ldots \tau_{\max})]$ is the maximum value of such approximation function for argument range $<\tau_0\ \tau_{\max}>$ and $\mathrm{Min}[P_C^N(\tau_0 \ldots \tau_{\max})]$ analogous minimum value.

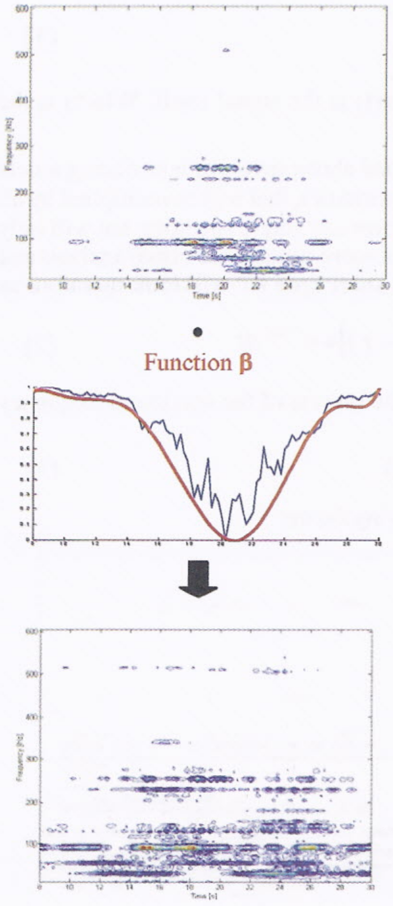

Fig.4. Application of β function in the spectrogram compensation process

The application of thus created function ß(.) is shown on figure 4. The topmost image shows the original spectrogram, the middle one presents the compensation function (red color) and the bottom one shows the result of their multiplication. Again it is visible that the resulting, modified spectrogram carries more visual information regarding the changes that assuming the "stationarity" of the environmental conditions may be attributed to changes that occurred in the propulsion characteristics of the source of the acoustic signal.

2. CONCLUSIONS

The method for the modification of spectrograms presented in this paper has been primarily developed for the purpose of better visual analysis of the investigated signal coming from a moving source generating a non-stationary signal. It significantly improves a qualitative analysis of such hydroacoustic data and if we assume that the wave propagation conditions remain constant it is also possible to study "compensated" spectrograms from the quantitative perspective. Further analysis is necessary to verify the benefits of this method in the fields of object classification, motion properties extraction, application of neural network technology.

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