DECOMPOSITION OF UNDERWATER SIGNALS ON BOUNDED DOMAIN FUNCTIONS

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1 - INTRODUCTION

Underwater interception is a field that concerns detection and classification of sonar signal. In most situations, the discrimination is realised from comparisons between parameters as frequency, duration and context where signals spread. Now, technology is such as transmitters can generate complex signals, composed of wave trains, called "stage" of emissions, whose features can be changed from an emission to another, and even can be like those of others transmitters. So sonar interception have a problem of target confusion.
This paper concerns detection then classification of almost similar signals but belonging to two different families called " kind one" and "kind two" family. Every family contains a set of signals whose each signal is composed of one or several stages of straight or modulated frequency.

A decomposition on Morlet wavelets is realised in order to analyse the raising power phase. Its permits to show that for kind one of transmitter, the raising power phase contains a frequency sliding. Adding this characteristic to the wavelet constition, we develop a new transformation.

By assuming that transmitter is equivalent to a second order system, we realise an adaptative decomposition on particular functions in order to distinguish sonar emission to its reverberation.

2 - ANALYSIS OF THE RAISING POWER PHASE

2 - 1 - Using of the Wavelet Transform

The wavelets transform, introduced by Morlet realise on signal x(t) the following operation [7, 8] :

$$C_x(t,a) = \int_{-\infty}^{+\infty} x(\tau)\, g_a^*(\tau - t)\, d\tau \qquad \text{with} \qquad g_a(\tau - t) = \sqrt{a}\, g(a(\tau - t))$$

The parameter 'a' corresponds to the compression coefficient, and 't' corresponds to the time delay. g(t) is called analysing wavelet.
So, the quality of transformation depends on the wavelet choice.

Visualisation of available signals have permited to show that the raising power phase could be approximed by a gaussian.

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So, the chosen wavelet is Morlet's kind : $g(t) = e^{-\alpha t^2} e^{2i\pi f_0 t}$ (1)

where 'f_0' is the central frequency of sonar signal and 'α' must characterise the raising power phase.

Experimental studies and sampling period have shown that a good choice of 'α' corresponds to wavelet life equal to $5 / f_0$.

This leads to relation ,

$$e^{-\alpha\left(\frac{x}{2f_0}\right)^2} \approx \frac{1}{N} \quad \text{, N arbitrary} \qquad \text{so} \qquad \alpha \approx \left(\frac{2f_0}{x}\right)^2 \ln N \qquad (2).$$

If we call x(t) the signal, his transformation corresponds to the convolution product :

$$d(t, a) = \int_{-\infty}^{+\infty} x(v)\, g_a(v - t)\, dv \text{ ,} \qquad \text{that can be written ,}$$

$$d(t, a) = \int_{-T_a}^{Ta} x(u + t)\, g_a(u)\, du \qquad (3) \qquad \text{with} \qquad T_a = \frac{2,5}{af_0}$$

The energy of the function $g_a(u)$ changes with 'a'. The energy of x(t) into the interval $[-T_a, T_a]$ changes also in the transient phase of raising power. So it is desirable to replace d(t,a) by the coherence function defined by

$C(t, a) = C_1(t, a) + i\, C_2(t, a)$, where

$$C_i(t, a) = \frac{\int_{-Ta}^{Ta} x(t + u)\, e^{-\alpha a u^2}\, hi(2\pi a f_0 u)\, du}{\sqrt{\int_{-Ta}^{Ta} x^2(t + u)\, du}\ \sqrt{\int_{-Ta}^{Ta} e^{-2\alpha a u^2}\, hi(2\pi a f_0 u)^2\, du}} \qquad (4)$$

with $h1(t) = \cos t$, $h2(t) = \sin t$

The chosen graphic representation, shows in form of contour lines, the evolution of the square modulus of C(t,a) during the time.

So, one can note, for kind one signals, an important frequency drift corresponding to the raising power phase *(cf fig 1, 2)* .

We don't generally see it for kind two signals *(cf fig 3, 4)* .

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2 - 2 - The Analysing Wavelet contains a modulated frequency

The interest of the wavelet transform is to decompose signals on a set of bounded domain functions. Applied to sonar signals, it permits to characterise one of the two kinds of available emissions by a frequency drift contained in the raising power phase. So comes the idea to included this modulation, that we assume linear, in the analysis wavelet creation.

So we define a function $g(t) = e^{-\alpha t^2} e^{i(2\pi f_m (1+kt)t)}$,
whose instantaneous frequency is $f_i = f_m + 2 k f_m t$,
where 'α' is the deadening factor, 'k' is the increasing coefficient of the modulation, f_m is the medium frequency of modulation.

In order to define the modulation of one category of transmitters, we find a signal with a good rate signal on noise, and we determine the beginning frequency f_d and the final frequency f_f of modulation, and the number of periods 'x', of medium duration T_m, in order to reach f_f.

Supposing that the modulation is linear, we define the coefficient k by relation :

$$k = \frac{f_f - f_d}{2x}.$$

Experimental studies show that x is equal to five.

The deadening coefficient is infered as following :

$$\alpha = \left(\frac{2}{x T_m}\right)^2 \ln(N).$$

The analysing wavelet can be written :

$$g(t) = e^{-\left(\frac{2}{x T_m}\right)^2 \ln(N) t^2} \cdot e^{i\left(2\pi f_m\left(1 + \frac{f_f - f_d}{2x} t\right)t\right)}$$

In order to shake of the amplitude of signal, we use the same process of transformation and representation as previously.
This representation still shows presence of a frequency drift included in the raising power phase for kind one signals *(cf fig 5, 6)*. We don't generally see it for kind two signals *(cf fig 7, 8)*.

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3 - ADAPTATIVE DECOMPOSITION ON SECOND ORDER FUNCTIONS

3 - 1 - Principle

We suppose that the oscillating systems of transmitters are second order circuits composed of inductance-coil, resistance, capacitor, such as sonar signal is proportional to the tension applied to the charge resistance R [1,2] .

We can write it : $S(t)=ke^{-\alpha t}\sin\omega t$.

So, we suppose that another system provides periodic excitations in order to generate the sonar signal, and we can consider sonar emission as a train of deadened sinusoids. So, the end of the stage can characterise the excitator system stopping, that is to say the attenuation coefficient of resonator circuit. In order to distinguish the emission to its reverberation, it must bring out this decreasing, and so decompose signals on functions defined by :

$$o_s(t)=\begin{cases} e^{-at}\sin\omega t & \text{if } t\geq 0\\ 0 & \text{if } t<0\end{cases} \quad \text{or} \quad o_c(t)=\begin{cases} e^{-at}\cos\omega t & \text{if } t\geq 0\\ 0 & \text{if } t<0\end{cases}$$

The projection of the signal x(t) on these functions can be written :

$$F(t,\alpha,\nu)=\int_{-\infty}^{+\infty} e^{-s(\tau-t)}x(\tau)\,d\tau \qquad \text{with } s=\alpha+2i\pi\nu$$

$$F(t,\alpha,\nu)=\int_{t}^{+\infty} e^{-s(\tau-t)}x(\tau)\,d\tau$$

That corresponds to the Laplace transformation [3].

This projection is not easy to show , so we are inspired by the wavelet transform philosophy [9,10] and we impose with adaptative way relation between deadening factor α and the frequency ν as following :

At every time t, we experimentaly determine functions $\alpha_r(\nu)$and $\alpha_i(\nu)$ such as :

$$\Re(F(t,\alpha,\nu)) \leq \Re(F(t,\alpha_r(\nu),\nu))$$

$$\Im(F(t,\alpha,\nu)) \leq \Im(F(t,\alpha_i(\nu),\nu))$$

where $\Re$ et $\Im$ correspond respectively to real and imaginary parts.

We must introduce following functions:

$$X_r(t,\nu)=\int_{t}^{+\infty} e^{-\alpha_r(\nu)(\tau-t)}\cos(2\pi\nu(\tau-t))\,x(\tau)\,d\tau$$

$$X_i(t,\nu)=\int_{t}^{+\infty} e^{-\alpha_i(\nu)(\tau-t)}\sin(2\pi\nu(\tau-t))\,x(\tau)\,d\tau$$

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Pratically, we compute the estimate of Xr and Xi by relations :

$$\tilde{X}_r(t,v) = \int_t^{t+T} e^{-\alpha_r(v)(\tau - t)} \cos(2\pi v(\tau - t))\, x(\tau)\, d\tau$$

$$\tilde{X}_i(t,v) = \int_t^{t+T} e^{-\alpha_i(v)(\tau - t)} \sin(2\pi v(\tau - t))\, x(\tau)\, d\tau$$

where T must be well chosen depending on α_r, that depends on the time t .

The chosen graphic representation, shows in form of contour lines, the evolution of the function M(t,v) that corresponds to a modulus of a complex number.

$$M(t,v) = \sqrt{X_i^2(t,v) + X_r^2(t,v)}$$

3 - 2 - Results

This decomposition brings out the end of stages, and permits to distinguish sonar emission to its reverberation *(cf fig 9 to 11)*. Moreover it shows the presence of a frequency drift included in the transient decreasing phase for signals belonging to the family "one" *(cf fig 9, 10)*.

4 - CONCLUSION

These two experimental methods that are inspired by the wavelet transform philosophy are very interesting for two points:
Decomposition on modulated or straight frequency wavelet permits to show a transient linked to one category of signals.
Then, decomposition of signal on second order functions permits to distinguish sonar emission to its reverberation. Moreover it brings out a frequency drift included in the transient phase of decreasing for signals belonging to one family of signals.

5 - BIBLIOGRAPHIE

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Figure 1 : Transformation de Aa11

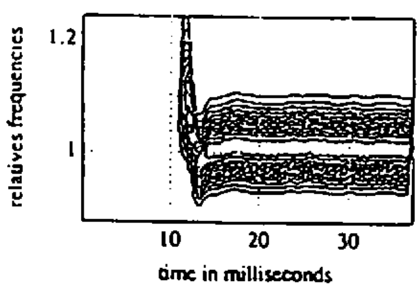

Figure 2 : Transformation de Ab1

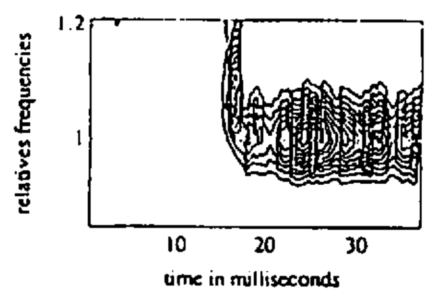

Figure 3 : Transformation de Bq1

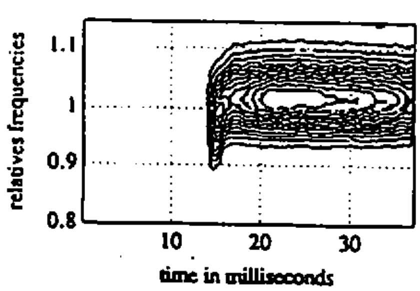

Figure 4 : Transformation de Bu41

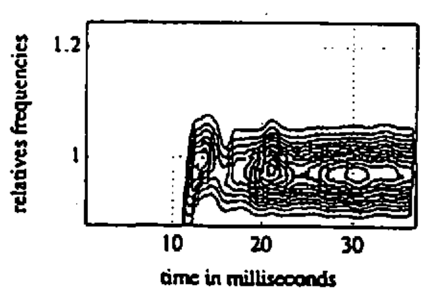

Figure 5 : Transformation of Aa11

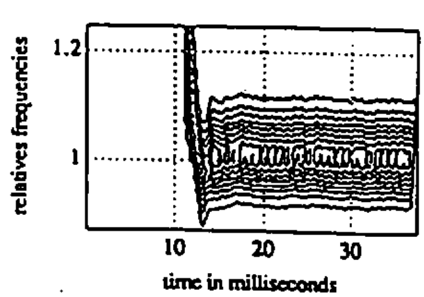

Figure 6 : Transformation of A15a1

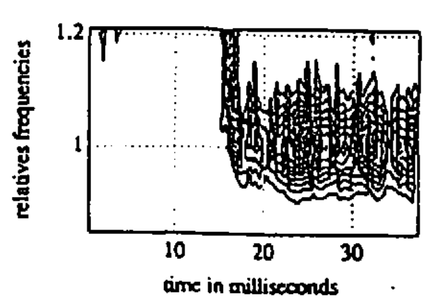

Figure 7 : Transformation of Bq1

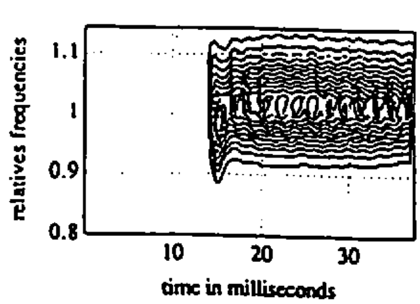

Figure 8 : Transformation of Bu1

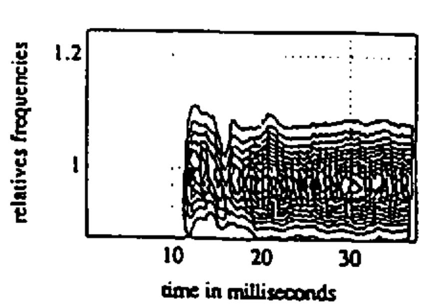

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Fig9, Adaptative transformation of A15

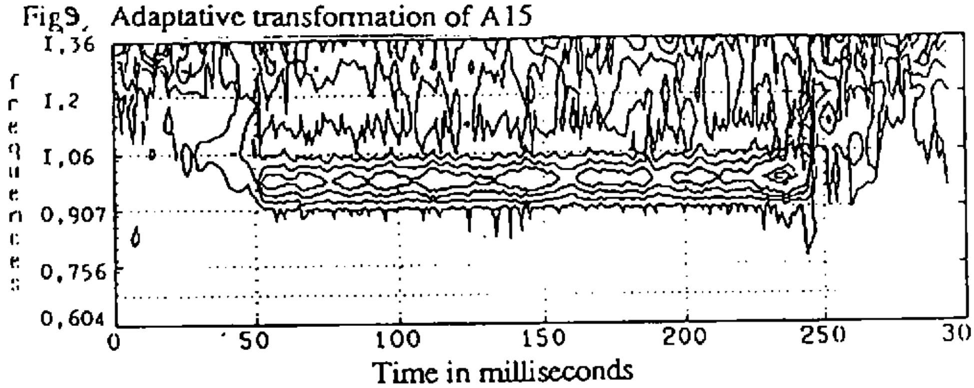

Fig 10 Adaptative transformation of A17

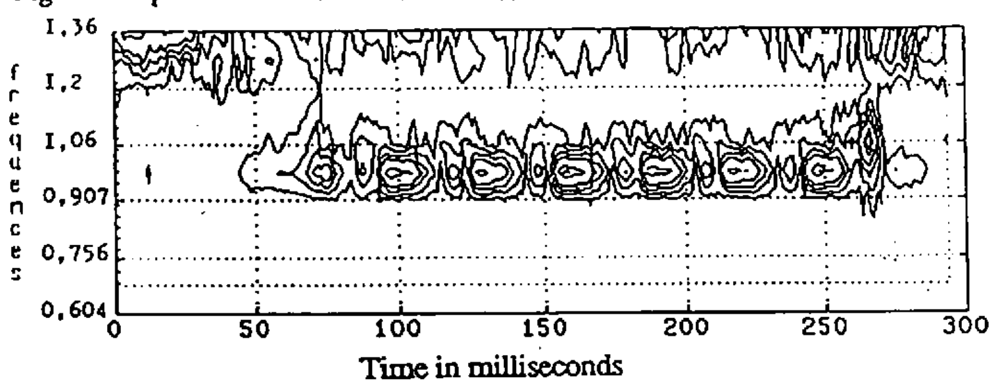

Fig 11 Adaptative transformation of Bc1