the sonar is moved, step by step in both horizontal directions (x,y), near over the water/sediment interface. The frequency of the signal is low enough to penetrate the sediment without important attenuation, and the object if the reflection coefficient of its material is smaller than one. Thanks to the narrow beamwidth, a small surface of the object is insonified: we can therefore realize multiline vertical scans over the object as shown in Fig. 3.

B. *Example of Real Data.*

Following processings are based on simulated data and on real data collapsed during trials made in a pool. Fig.3 shows a single line scan of a water-filled cylinder target buried in sandy sediment. One can clearly notice the water/sediment interface, and the two interfaces of the object.

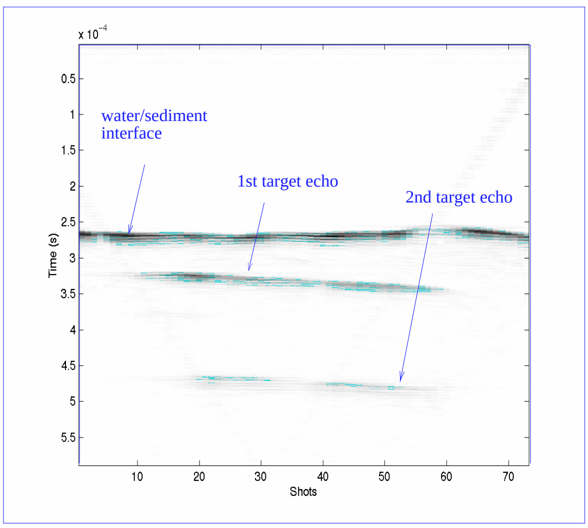

Fig. 3. Experimental result: water filled cylinder

III. CLASSIFICATION

A. *Echoes Separation.*

In spite of the good resolution of the beam, one is faced to a problem of temporal resolution; indeed, in order to be transmitted by the sediment or the material of the object, the emitted frequency must be low which means that the wavelength is necessarily higher than dimensions of the shell of the objects. Moreover, dilatational wave speed in materials like aluminum is around 6300 m/s (in normal incidence, shear waves are neglected).

For instance, it remains difficult to separate echoes from different shells of some object with low dimensions, or echoes reflected by both interfaces of a shell of the object (sediment/shell and shell/water interfaces for a water filled object).

Being able to separate echoes reflected by both interfaces of a same shell may be a mean of classifying manufactured targets: indeed for this kind of object, these echoes should appear at each shot unlike natural targets such as boulders.

In order to improve the temporal resolution, matched filter is usually applied since the correlation peak is generally narrow; however, as shown in Fig. 4, the correlation peak of the ricker is as large as the main peak of the original signal: Fig. 4.c is the result of the matched filter applied on a signal with two rickers separated with three samples; it is clearly impossible to distinguish them: in this case, the matched filter is not efficient enough. A way of solving this problem is to apply a time delay estimation by using Higher-Order Spectra Analysis.

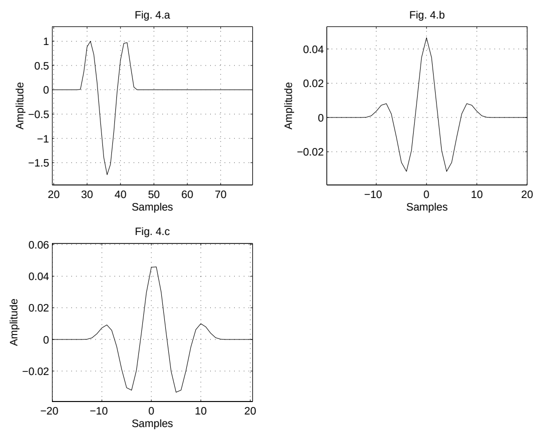

Fig. 4. a : Ricker - b : Autocorrelation Function - c : Matched Filter Result

B. *High-Order Spectra Analysis.*

One of the usual application of the Higher-Order Spectra (also known as Polyspectra) is the estimation of time delay between two sensors. The idea is to use the same processing by considering an observation signal and a reference signal (the emitted ricker). In general, the principal motivation behind the use of polyspectra analysis in signal processing is the suppression of Gaussian noise processes of unknown spectral characteristics in detection, parameter estimation and classification problems. However, in this work, the motivation is based on a comparison between the quality of the estimations of the power spectrum (order=2) and the Bispectrum (order=3).

A complete description of Higher-Order Analysis is given by [4].

The bispectrum of a signal x given by (1) is defined as the bi-dimensionnal Fourier transform of the third-order cumulant sequence described in (2).

$$\mathcal{C}_3{}^x(\omega_1, \omega_2) = \sum_{\tau_1=-\infty}^{+\infty} \sum_{\tau_2=-\infty}^{+\infty} C_3{}^x(\tau_1, \tau_2) e^{-j(\omega_1\tau_1+\omega_2\tau_2)} \quad (1)$$