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EXPERIMENTAL HIGH ACCURACY MEASUREMENT IN ULTRASONIC COMPASS

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Abstract – A procedure to identify useful echoes parameters pre-estimation in an ultrasonic signal, to allow the application off line of a Modified Maximum Likelihood Estimator (M.L.E.) [1] as been faced. An experimental application, utilizing an ultrasonic medical scanner, sampled by an acquisition board is also presented.

Keywords: echoes parameters, high resolution, image enhancement.

1. INTRODUCTION

When slabs with different mechanical impedance make up a material, an incident wave can be partially reflected and absorbed by each interface, giving rise to multiple echoes [1]. Useful echoes characterized the position of the interfaces whereas multiple ones are considered noise, but are difficult to be recognized. In Fig.1 is shown an example of a structure under test, assuming the probe scans the object by the main lobe perpendicularly oriented to the interfaces, both in transmission and in detection, underlining all possible paths generated by two discontinuities in mechanical impedance.

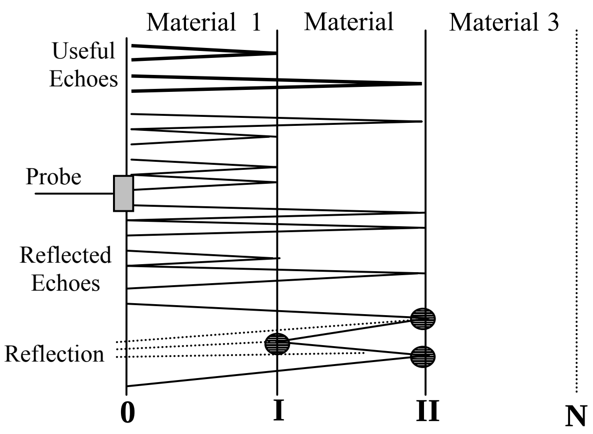

Fig.1: Simple structure with useful and multiple echoes

This problem concern all ultrasonic signal analysis in many different fields like medical applications, industrial processes, geological examination etc., but it becomes relevant in structures where mechanical discontinuities are very close: the eyes, the skin, the archaeological artifacts etc.. The problem, well known since 70's, was ignored because of the great computational load not bearable at the time [2][3]. In seismology the use of two-dimensional array of sensors makes less pressing the problem [4] because the receivers spatially separation from acoustic wave sources. Electro–acoustic equivalence establishes a correspondence between acoustic wave propagation in a structure and electromagnetic wave propagation in a delay line. By means of this equivalence and considering reflection phenomenon only, we are able to realize a paths matrix (Fig.2) that describes all situations that can be encountered in an ultrasonic (U.S.) exploring signal. Identifying signal's maxima, we can order in time the rows of a paths matrix using an algorithmic filter. It identifies the first two signal's maxima caused by the two first distinct walls and considers these like the first two useful echoes. Then, it evaluates positions of multiple echoes dependent on previous ones. Subtracting from signal such echoes (useful and multiple), the residual starts from an echo that is not eliminated. After, it verifies that in such residual the third useful echo had not been erased. Such an identification causes the loop of the procedure, saving others certainly identified echoes both useful or multiple (Fig.3). The result of this procedure, rearranges the paths matrix and orders echoes by time, identifying useful echoes too.

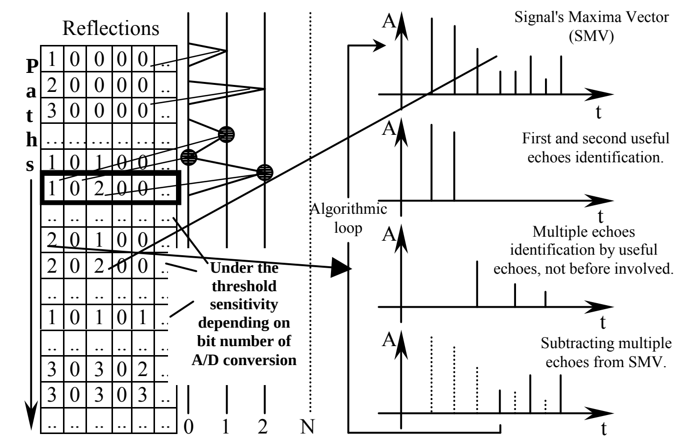

Fig.2: Paths Matrix. Fig.3: Algorithmic Filter

By means this algorithmic filter it is possible to detect position of multiple and useful echoes, corresponding to structure's discontinuities. Echoes are considered as gaussian profiled, characterized by time position, amplitude, and standard deviation. In order to accurately establish position and shape of the useful echoes, their parameters are determined by a convergent loop based on M.L.E., starting from pre-estimated values carried out by proposed filtering. By means of Fisher matrix inversion [1], this algorithm is able to make independent estimated errors of single parameters, allowing improving pre-estimated values every loop of the algorithm. The aim of the work is to apply the identification process to useful and multiple echoes on a real U.S. image.

2. MEASUEREMENT APPARATUS CALIBRATION

A medical U.S. scanner, an acquisition card, a computer, a conditioning stage and a proper target compose measurement apparatus. U.S. scanner is a "Leopard" series 2001, furnished by Brüel & Kjær Medical, especially suitable for little dimension structures, surgical use and in pediatrics. This scanner works with three different frequencies 5.5, 7, 8 MHz and a 128 piezoelectric elements linear probe. The scanning mode is "B" type and the typical resolution is 0.4 mm at 8 MHz. The device supplies a spatial peak pulse average intensity (I_{SPTA}) less than 720mW/cm^2 and a mechanical index (MI) less than 1.9, in agreement with Food and Drug Administration dispositions [6] that fix the maximum values admitted from human body. The scanner samples the signal at 6 MHz rate and 8 bits resolution. A proper application of M.L.E. needs a higher sampling rate and resolution than those provided by the U.S. scanner, therefore we use an external acquisition card. A PCI-DAS4020/12, four channels, 12 bits resolution and up to 20 MHz sampling rate acquisition card has been chosen [7]. More, an interface circuit, shown in Fig. 4, must be provided to avoid interference between A/D board and the echo graphic machine, obviously introducing contributions in noise.

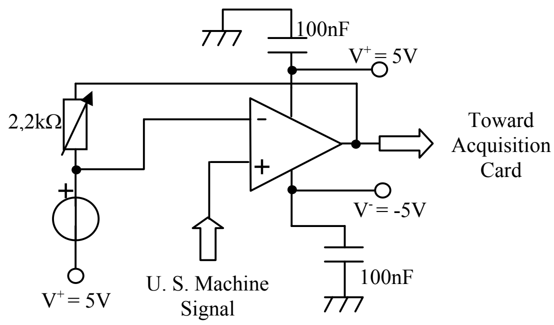

Fig. 4: A/D – echographic machine interface

Specific visual C++ software has been developed to manage the card. It allows acquiring a single image and saving it in an ASCII file. Trigger is activated by frame synchronism. A whole image takes 750 Kbytes. The M.L.E. algorithm requires the use of a PC with elevated performance. The target is composed by a thermoplastic pipe with internal diameter of 1,2 mm and external of 2 mm held in a plastic box (14,4 X 5,4 X 7,5 cm). We can see a view of the measurement apparatus in Fig.5, while in Fig.6 is represented the target and the U.S. probe. Figure 7 shows section's pipe and its shape in U.S. response. The probe is held, by means of a mechanical arm at the top of the box, in a central position with respect box's walls. We have filled up the box with water in order to improve acoustic conductivity and the pipe too has been filled up of water to make it as

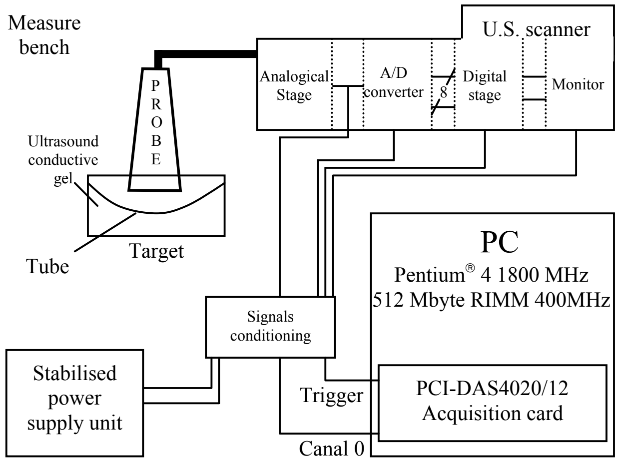

Fig.5 Measurement apparatus scheme.

similar as possible to a vein. Conditioning stage is necessary in order to make compatible the signal, coming from the U.S. scanner, with the input range of the acquisition card and to manage the U.S. scanner's timing that gives origin to the trigger.

3. EXPERIMENTAL RESULTS

The image in Fig.8 is composed by 250 lines each one composed by 2800 samples equivalent to a time interval of 140 µs. Considering the return path to the sensor at the speed of about 1500 m/s of ultrasound in water, 10.5 cm is the deep of the image. It shows clearly the pipe's shape.

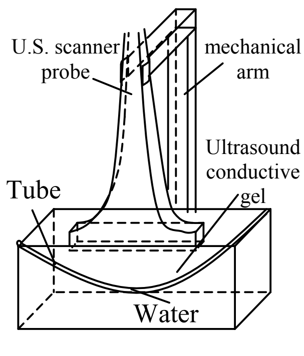

Fig.6: Target.

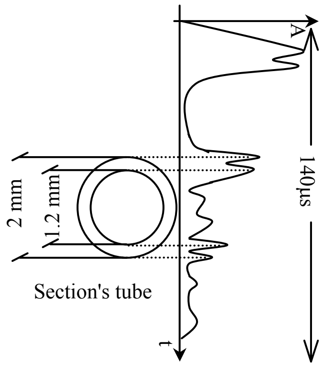

Fig.7: Correspondence between section's pipe and shape of U.S. response.

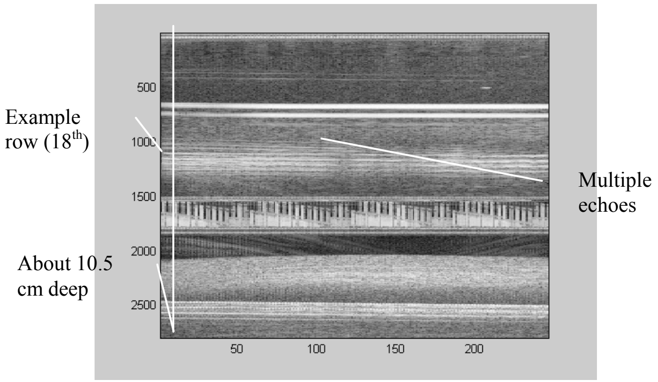

Fig.8: image of the phantom

The sampled signal considered optimising the procedure to useful echoes identification is the 18th raw that is shown in Fig. 9, where is possible both to see the signal manipulation of instrument to make more readably images and the noise on it identifiable.

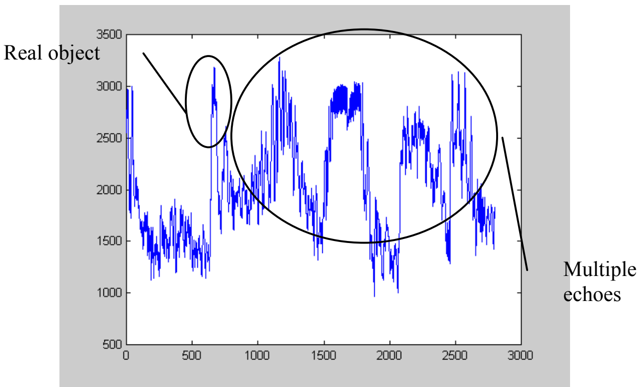

Fig.9: acquired signal (ordinate axe indicate the value in quanta while the abscissa axe indicate the time ordered sampling).

The pre-analysis of such a signal is necessary firstly insulating the noise due to both the instrumental N_{Instr} and to the physical phenomenon N_{Phis} and, after, cleaning signal Instr by the instrumental manipulation obtaining the pure physical behaviour Phys that will allows the useful echoes determination.

4. SIGNAL PRE-ANALYSIS

As indicated in the last paragraph, we can indicate the pick up signal as:

$$f(t) = Phys(t) + Instr(t) + N_{Instr}(t) + N_{Phys}(t) \qquad (1)$$

Evidently it is necessary to separate Phys(t) component to realize a pre-estimator allowing the identification of useful echoes. To operate such a separation we utilize the Wold theorem that assures deterministic and stochastic component of a signal are orthogonal with respect to data treatment methodologies. We consider a general approach to such a separation based on the polynomial best fit on data: the polynomial carried out will a part of the deterministic component. Complete separation of deterministic component could be obtained when the distribution of spreads around the polynomial will be Gaussian. In such a manner the stochastic component can be interpreted, in informative terms with the maximum of entropy. Problems arise when the samples number became very large and computing power does not support solving procedure of best-fit polynomials by the limited length of mantissa in mobile point calculation. So considerable polynomials cannot be greater than twentieth degree

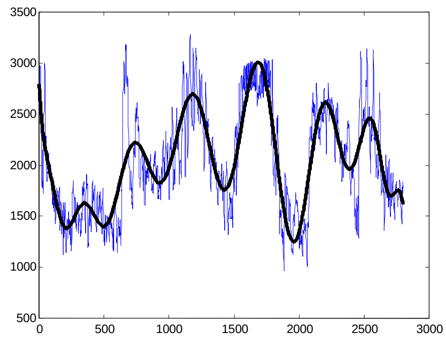

Fig. 10: twentieth degree polynomial gripping deterministic component information

This not assures the complete deterministic part separation, compelling to other procedure to separate the remainder of deterministic part operating on statistical part. Yet it is before necessary to separate in the noise, the instrumental contribution N_{Instr} on residual signal.

4.1 Noise component separation

The separation of the N_{Instr} by N_{Phys} is fundamental because only the last component can help to separate the remainder of deterministic part of the signal. In the scheme of occurrence can be written

$$N_{obs}(\xi) = \int_{-\infty}^{\infty} N_{Instr}(\lambda) \cdot N_{Phys}(\lambda + \xi) d\lambda \qquad (2)$$

where N_{obs} is the picked up distribution of noise, ξ is the spread around the expected value, λ is the integration parameter all over the spreads, N_{Instr} and N_{Phys} are the distribution of noise components. To test the distribution of N_{Instr} noise signals, we refer to a normality distribution. The N_{Instr} = 1125 samples are grouped into k intervals to built the frequency histogram. Determined the mean m_{INstr}=1359 quanta and the standard deviation s_{Instr}=237.5 quanta, the number of intervals is determined by formula [8]:

$$k = \sqrt{\frac{N+195}{1.4}} \qquad (3)$$

that in our case is k = 31. The samples number falling into the i-th interval is the occurrence and will be denoted by f_i, while the expected one is F_i, that can be calculated by the

$$F_i = \frac{N_{Instr}}{\sqrt{2\pi} s_{Instr}} \int_{a_i}^{a_{i+1}} e^{\frac{(\xi_i - m_{Instr})^2}{2 s_{Instr}^2}} d\xi_i \qquad (4)$$

assuring always both

$$f_i \geq 5 \quad \text{and} \quad F_i \geq 5 \qquad (5)$$

being a_i and a_{i+1} the absolute limits of the i-th interval compatible with (5). News about N_{Instr} can be obtained from the part of analogical signal surely due to instrumental noise alone that can be isolated in the queue well beyond the deep explored by the echo graphic machine as shown in Fig. 11. The signal distribution is shown in Fig. 12 in which is also presented the expected Gaussian distribution. In experimental conditions the distribution is not a physical observable. We only can count the events into an interval corresponding to is the occurrence.

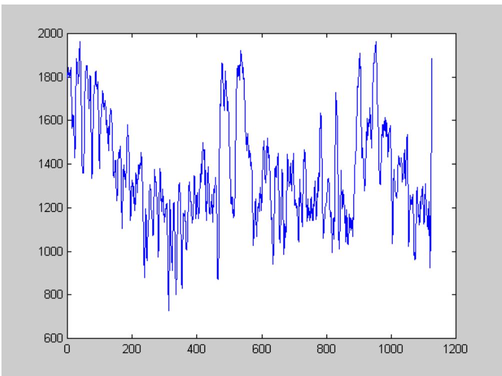

Fig. 11: instrumental noise on a sampled record that is the queue of signal represented in Fig. 9 (ordinate axe indicate the value in quanta while the abscissa axe indicate the time ordered sampling). The mean value is 1359 quanta.

The relation (2) can now be written in the form

$$\Delta N_{obs}(\xi_i) = \frac{\sum_{j=1}^{n} \Delta N_{Phys}(\xi_i) \cdot \Delta N_{Instr}(\xi_j) \left[\operatorname{erf}\left(\frac{a_{j+1}}{\sigma_{obs}}\right) - \operatorname{erf}\left(\frac{a_j}{\sigma_{obs}}\right) \right]}{\sum_{j=1}^{n} \Delta N_{Instr}(\xi_j)} \qquad (6)$$

being a_i interval limits to determine the experimental occurrence of n intervals, where $a_0 = -\infty$ and $a_n = +\infty$ related to ξ_i and ξ_j by the

$$a_i < \xi_i \leq a_{i+1} \quad \text{and} \quad a_j < \xi_j \leq a_{j+1} \qquad (7)$$

with σ_{obs} the standard deviation determined by sampled data. To avoid problems with corners occurrence calculation, the mean of ΔN_{Phys} is located in correspondence of the least value encountered in i = 1 interval and the greater value encountered in i = n interval; outside the mean value is positioned in the central value of the interval.

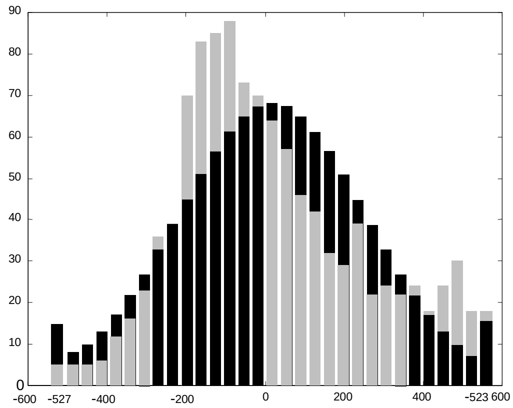

Fig. 12: samples occurrence in N_{Instr} related to Fig. 11 sampled Signal (ordinate axe indicate the number of occurrence). Black columns indicate the Gaussian distribution occurrence, while the grey columns indicate the experimental occurrence).

The relation (6) can be interpreted as a system allowing isolating the N_{Phys} real occurrence. It easy to observe that noise is not gaussian.

4.2 Deterministic component carried out by the noise occurrence due to physical process

Expecting that useful deterministic signal again hidden on the physical noise component is overlapped to a pedestal, we examine the occurrence of samples located at the extremes positive spread intervals in such an occurrence histogram. Samples located here, more than statistically expected, will be considered deterministic and added to the polynomial already determined.

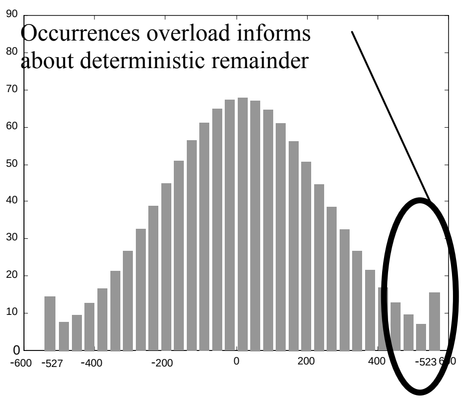

Fig. 13: operating procedure indication separating deterministic information hidden in noise

5. USEFUL ECHOES PARAMETERS PRE-ESTIMATION PROCEDURE

After having determined from data, Instr(t) component, considering the physical behavior of ultrasound in water, the signal intensity, must be on time dependent. In fact time elapsing corresponds to higher distance of target giving echoes, meaning higher attenuation. Such a phenomenon is characteristically exponential, so the ln[Instr(t)] must have a linear behavior in function of time.

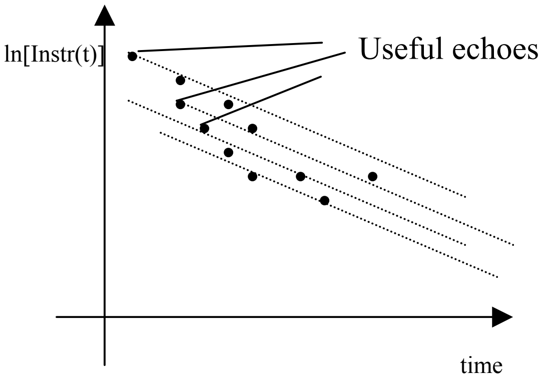

Fig. 14: useful echoes identification procedure

The echoes signal pick up must be much more attenuated greater is the time ultrasound passing through the matter. All echoes involving the same walls reflections must be positioned in such a semi-logarithmic diagram, on a right line with the same trend parallel each other. The first occurrence of an echo of such a right line could represent the determination of the useful one. This method is a trivial version of well known Cepstrum procedure, avoiding the problem that foreseen convolution, between the picked up signal and the stimulus, gives a great number of line in the Fourier transform of the logarithm of the signal, making difficult the interpretation, due to the fact the reflected signal does not preserve the characteristic of the stimulus.

6. CONCLUSIONS

The problem of high accuracy on identification of useful echoes of real U.S. scanner signal has been faced. The measure accuracy is enhanced of one or two orders of magnitude with respect to commercial apparata. By means of this procedure it is possible to develop innovative lines of diagnostic research that use information, like multiple echoes, actually neglected.

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