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COMPARISON BETWEEN THE METHODS OF THE NORM L1, L2, HILBERT TRANSFORM AND PHASE ANALYSIS TO OBTAIN THE TIME OF FLIGHT OF ULTRASONIC SIGNALS

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ABSTRACT

Some techniques to estimate the time of flight (TOF) allow getting a larger resolution, more than a sampling period. Therefore, it is possible to obtain a greater accuracy in the measurement of acoustic parameters using the TOF.

In this work a comparison between the mentioned methods is carried out; analyzing the standard deviation of the time of flight in relation to the sign to noise ratio (SNR) between 5 dB to 40 dB and a bandwidth of 4 MHz, 5 MHz and 6 MHz to -6 dB of simulated ultrasound signals, with the purpose of analyzing the performance of each method.

The results demonstrate that the method of the phase estimation presents the bigger values of standard deviation.

For high-SNRs the methods of the L1 and L2 norm present similar values; furthermore, they exhibit the lowest values of standard deviation of the TOF estimation of the four methods.

Finally, it was observed that for low SNR the method of Hilbert transform allows to obtain values of standard deviation similar to the methods of the norm L1 and L2 with a smaller time of processing of the signal.

INTRODUCTION

The quantitative analysis of the alterations that suffers a pulse of ultrasound when it propagates through a tissue can provide information of qualitative parameters of them. Therefore, it allows distinguishing various pathologies [1, 2, 3]. One of the first measurements realized systems scanner type A is the Time Of Flight (TOF) of an echo of ultrasound, with the purpose of obtaining the velocity of the medium.

Occasionally, other characteristics (attenuation, dispersion, etc.) of the echo are used; and not only the position of the echo like in the TOF.

These characteristics give the necessary information of the medium from the propagation of the front of waves ultrasonic that permit distinguishing, indirectly, some important tissue’s features, as: the quantity of the proteins in the tissue [4], the quantity of collagen in the tissue [5], the elasticity [6], among others.

Because it is expensive in time and human resources getting the time of flight of the ultrasonic signals manually, it is necessary to develop algorithms to obtain it automatically. Some of them estimate these times with a higher resolution than the sampling period [7, 8, 9, 10].

In this work, it is analyzed the efficiency of the following methods: norm L1, norm L2, phase analysis[7], Hilbert transform[10], making a comparison of the deviations in the estimate of the time of flight in relation to the changes of the SNR and the bandwidth of simulated ultrasound signals.

MATERIALS AND METHODS

Mathematical model of the reference signal

One algorithm was implemented for the evaluation of the methods presented that permit to get simulations of ultrasound waves by means of the mathematical model [7]:

$$p = -Ae^{\frac{-BW^2([0,tm,2tm,...,Td]-tr)^2\pi^2}{12\ ln(10)}} \sin\left(2\pi\ fc\ ([0,tm,2tm,...,Td]-tr)\right) \qquad \text{(Eq. 1)}$$

Where: p = simulated sound wave.
A = maximum amplitude of the signal.
Fc = central frequency of the pulse.
BW = bandwidth of -6 dB.
Tm = time of sampling.
tr = time of flight.
Td = time of duration of the signal.

One hundred signals, with variations in signal to noise ratio (SNR), in the ranger from - 5 dB to 40 dB; and 10 signals for each bandwidth: 4 MHz, 5 MHz and 6MHz. Furthermore, depending on the analysis, the chosen values for variables were: A = 1 Volt, Fc = 5 MHz, BW = 5.2 MHz, Tm = 1000 MSPS, tr = 1 μs, Td = 2.5 μs.

The samples generated by this algorithm were added with a component of noise, not correlated with the signal and with a normal distribution. The signal to noise ratio was obtained with the following equation [11]:

$$SNR = 10\log_{10}\left(\frac{\sum_{n=0}^{N-1} p^2(n)}{\sum_{n=0}^{N-1} g_s^{\ 2}(n)}\right) \qquad \text{(Eq. 2)}$$

Where: p = simulated sound wave
g_s = introduced noise
SNR = signal to noise ratio

Method of the norm L1

In this method, values of delay are obtained by getting the minimal differences between the acquired and the reference signals. The phase of the reference signal is varied iteratively and it is obtained the sum of the absolute value of the subtraction between the acquired signal and the reference signal. Then, the minimum of this new signal is obtained as the position of the ultrasonic echo. The method allows working on the signals of ultrasound or by means of theirs envelopes.

Method of the norm L2

This method, just like the norm L1, gets the difference between an analytical signal (whose phase varies iteratively) and an ultrasound signals; nevertheless, here the sum is the square of the subtraction between the signal of ultrasound and the reference signal.

The norm L2 presents better accurate results, but these are very dependent of the number of bits of the data, frequency of sampling and signal to noise ratio; then, it cause an intense computational load [9].

Phase analysis method

The analysis in frequency is used in this method, in which it is obtained the subtraction of the spectrum of phase of a signal; later the time of flight becomes the slope of the resulting straight line from an adjustment of minimal squares, in an interval around the central frequency.

Unlike from other methods based in displacement of phase, the value of obtained delay is not periodic, and the range of measure is not limited by the wavelength of the used signal.

Hilbert transform method
This method is based on using the crossed correlation between a referential echo's signal of ultrasound and the Hilbert transform (analytical signal), and it is assumed that the signal is narrowbanded, then it is possible to obtain the time of delay with minor resolution than one sample, by means of the following formula [10]:

$$delaytime = \frac{1}{w_o} \arcsin\left(x * h(r)\right) \qquad \text{(Eq. 3)}$$

Where: w_o = angular central frequency.
x = ultrasound signal.
$h(r)$ = Hilbert transform of referential signal.

It is necessary to obtain the delay previously, with an approximation as close as possible to the signal of ultrasound (with a minor error than 1/4 of the central frequency [10]); thus the calculated value is the delay sub-sample, which is why it will be added to its first calculated delay.

RESULTS

Results of the time of flight estimation

There were obtained TOF values for the four methods implemented and the standard deviation was taken with respect to the real value of time of delay generated (Figure 1).

From Figure 1 the following characteristics are observed:

- It is observed, in all the methods, a decrease at the standard deviation of the estimate of the time of flight as the SNR increases.
- The method of the phase estimation presents a bigger standard deviation in the TOF estimation, compared to the other 3 methods.
- For high SNR (above 35 dB), it is observed that the methods of the norm L1 and norm L2 maintain a constant standard deviation.
- The method of the transform of Hilbert, presents for low SNR, similar values to the norm L2; nevertheless, for high SNR the results do not tend to decrease their values of standard deviation as the method of the norm L1 or L2.

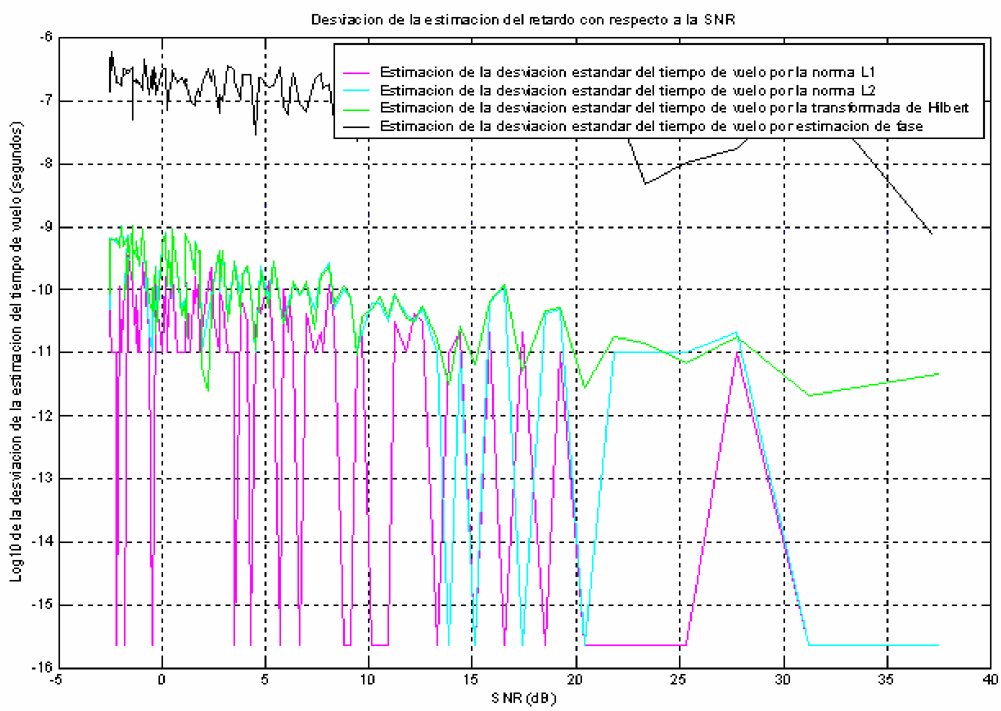

Figure 1.- Deviation of the estimate of the time of flight for each one of the methods in respect of different values of SNR.

Figure 2 shows the values of the estimated time of flight with regard to the change in the bandwidth of the signal, at 30 dB, it is observed that:

- The method that has the smallest deviation of the time of flight with respect to the change in the bandwidth is the method of the norm L2, followed by Hilbert's method, the method of the norm L1 and finally the method phase analysis
- All methods present a decrease at the standard deviation of the estimate of the time of flight as the bandwidth increases.

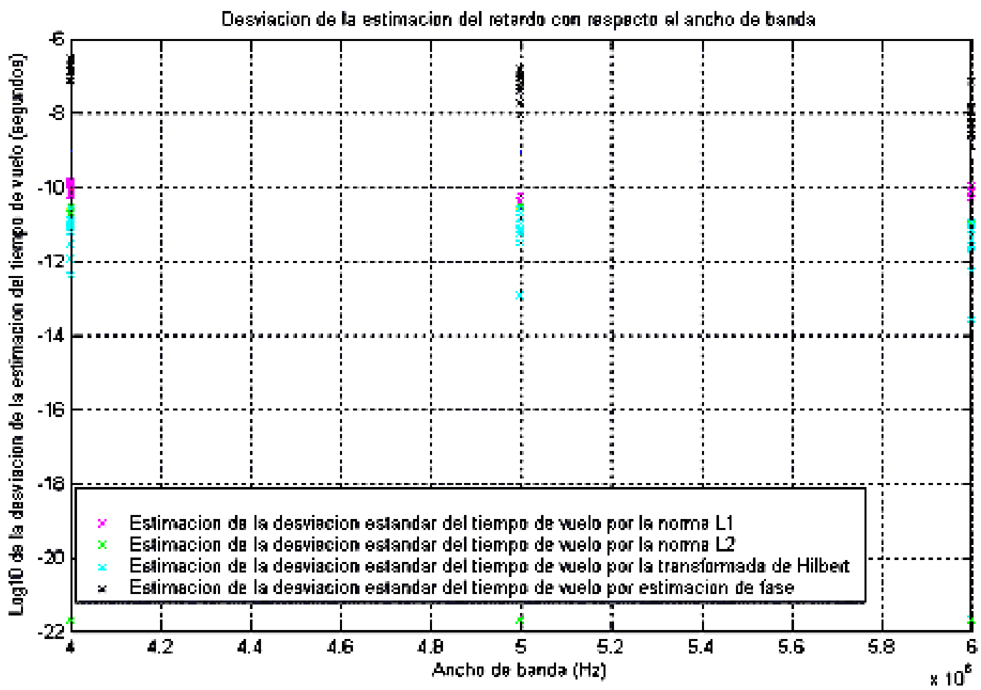

Figure 2.- Deviation of the estimate of the time of flight for each method in relation to different values in the bandwidth.

CONCLUSION

The developed algorithms permit to get the time of flight, with resolutions smaller than the time of sampling, with respect to the signal to noise ratio (SNR) and to the bandwidth. It can be observed that:

- In general, a tendency was observed to the increase in the error of the time of flight estimated in agree it diminishes its signal to noise ratio, or as the bandwidth decreases.
- In the low signal to noise ratio is better to use the method of the norm L1 since you have minor errors of standard deviation of the time of flight with respect to the time of real flight.
- The values of error found among the method of the norm L1, the method of the norm L2 or the method of the Hilbert transform in low values of SNR is approximated the time of sampling (1 ns)
- Furthermore, the three methods mentioned before, really permit to get values with smaller resolutions than one sampling time; however, the method of phase does not give smaller values than one sample, since its standard deviation of time estimate of flight is bigger than one time of sampling

Thus, according to the obtained results, for choosing the method to obtain of the time of flight is recommended to take into account:

- The signal to noise ratio (SNR).
- The bandwidth.
- The maximum error committed for the method when calculating the time of flight.

References:

[1] M. Moris, A. Peretz, R. Tjeka, N. Negaban, M. Wouters, P. Bergmann: Quantitative ultrasound bone measurements: normal values and comparasion with bone mineral density by dual x-ray absorptiometry, Calcified Tissue International **57** (1995) 6-10

[2] A. Giorgio, P. Amoroso, G. Lettieri, P. Fico, G. de Stefano, L. Finelli, V. Scala, L. Tarantino, P. Pierri, G. Pesce: Cirrhosis: value of caudate to right lobe ratio in diagnosis with US, Radiology **161** (1986) 443-445

[3] S. Panichkul, M Sripramote, N Sriussawaamorn: Diagnostic performance of quantitative ultrasound calcaneus measurement in case finding for osteoporosis in Thai postmenopausal women, J. Obstet. Gynaecol. Res. **30** (2004) **No. 6** 418-426

[4] S. Goss, L. Frizzell, F. Dunn, K. Dines: Dependence of the ultrasonic properties of biological tissue in constituent proteins, J. Acoust. Am. **67** (1980) **Issue 3** 1041-1044

[5] J. Mimbs, M. O´Donell, D Bauwens, J. Miller, B. Sobel: The dependence of ultrasonic attenuation and backscatter on collagen content in dog and rabbit hearts, **47** (1980) **No. 1** 49-58

[6] W. Svensson, D. Amiras: Ultrasound elasticity imaging, Breast Cancer Online **9** (2006) **Issue 06** e24

[7] A. Ibáñez, M. Parrilla, M. García, O. Martínez: Determinación del tiempo de vuelo de señales ultrasónicas con resolución superior a un periodo de muestreo por análisis de fase, Acústica 2000, II Congreso Iberoamericano de Acústica, Madrid, España

[8] I. Céspedes, Y. Huang, J. Ophir, S. Spratt: Methods for estimation of subsample time delays of digitized echo signals, Ultrasonic Imaging **17** (1995) **No.2** 142-171

[9] F. Viola, W. Walker: Comparison of time delay estimators in medical ultrasound, 2001 IEEE Ultrasonics Symposium 1485-1488

[10] A. Grennberg, M. Sandell: Estimation of subsample time delay differences in narrowband ultrasonic echoes using the Hilbert Transform Correlation", IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control **41** (1994) **No. 5** 588-595

[11] M. Vondrášek, P. Pollák: Methods for speech SNR estimation: evaluation tool and análisis of VAD dependency, Radioengineering **14** (2005) **No. 1**