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Ultrasonic Thermometry Inside Tissues based on High-resolution Detection of Spectral Shifts in Overtones of Scattering Signals

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Abstract

- **Some results of cooperation woks among current national projects of Mexico and Spain, are resumed. They are related to activities of three R & D groups, trying to achieve high-resolution ultrasonic thermometry inside tissue phantoms of a non-invasive way.**
- **Advanced spectral techniques are being used to extract thermal information in echo-signals acquired from biological materials having an internal quasi-regular scattering, for instance in liver, where a regular scatterers separation has been reported.**
- **These techniques could determine pathologies with thermal increases. Small changes with temperature of the resonance frequency overtones related to the mean reflectors separation can be detected, but the influence in detection of the echoes noise must be discarded.**
- **A first evaluation was made with echo-signals acquired from a phantom in the range (30°-45)°C; the noise influence is shown for distinct SNR, using signals derived of a mathematical model for hepatic tissue echoes, taken into account: average power, SNR and inter-arrival time standard deviation.**

Introduction and Antecedents

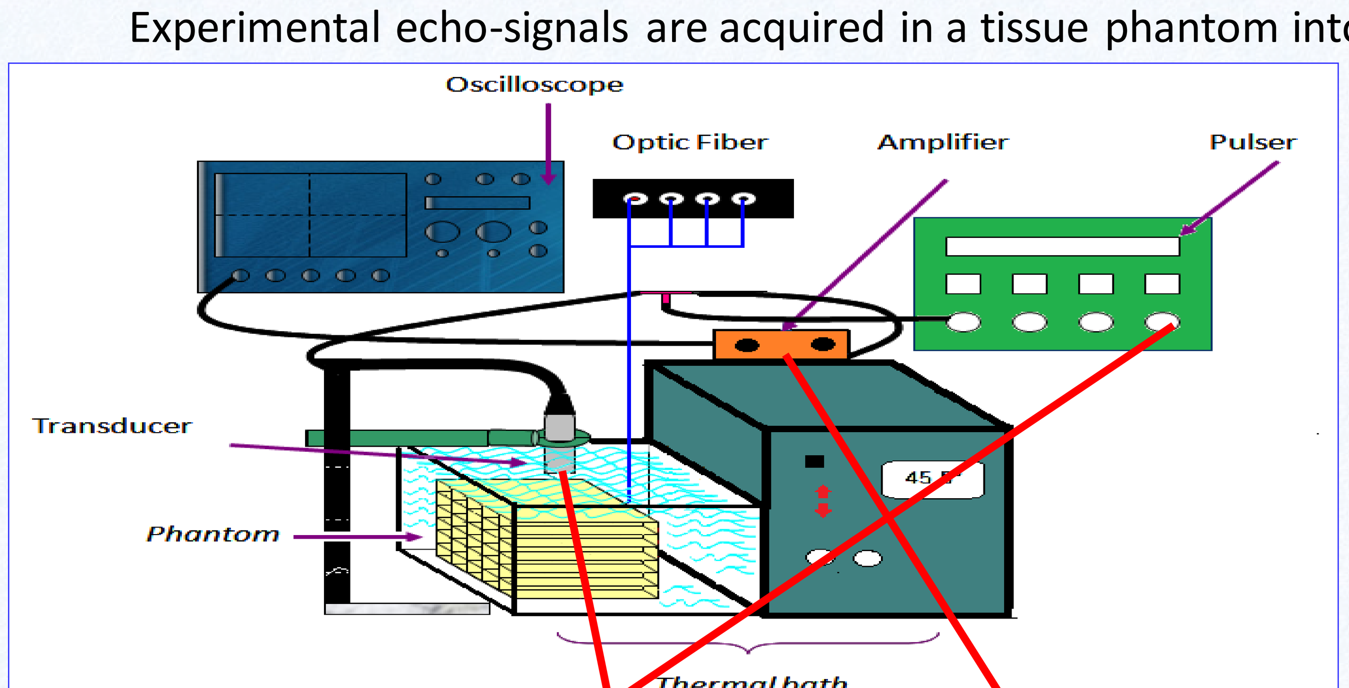
There is an increasing interest to ultrasonically obtain thermal information for diagnosis applications. This objective is performed by estimating the thermal influence on ultrasonic echo-signals. Distinct echographic imaging processing procedures, and time or frequency techniques for delay detection in echo-pulses, were proposed.

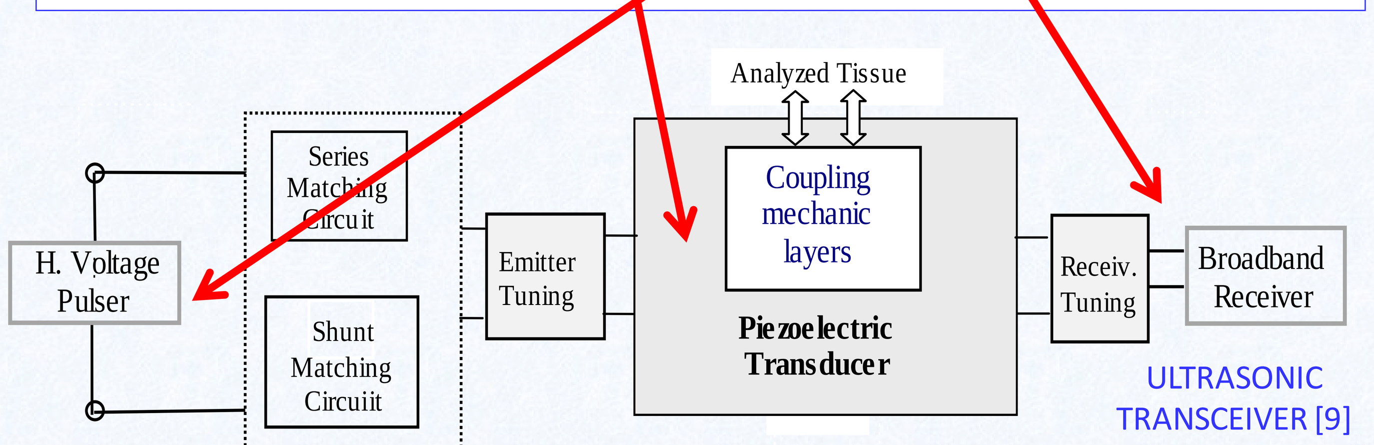
Processing of images from medical echography equipment was investigated, but it has serious limitations, because spatial resolutions related to density changes are usually worse than 500 microns, even working at relatively high frequencies (as 7 MHz). Ulterior studies, based on imaging segmentation algorithms [1-3] give spatial resolutions of ≈ 300 microns, but the thermal translations of these improved spatial resolutions, are not sufficient to obtain precision enough for ultrasonic thermometry with medical application (tenths of ºC).

Currently, variants of time and spectral analysis are been investigated related with internal scattering in tissues of quasi-regular distribution (e.g. in liver). They include proposals for tissue thermometry [4-8], employing a direct processing, in time or frequency domains, of the pulsed ultrasonic frames acquired from the medium, but investigating changes with the temperature suffered by other physical parameter distinct to the density. One advantage of this option is that it could be based on only one ultrasonic transceiver adding a sophisticated signal processing to achieve resolutions ranging around a few tenths of ºC. But this type of detection could depend of noise or interferences like signal jitter.

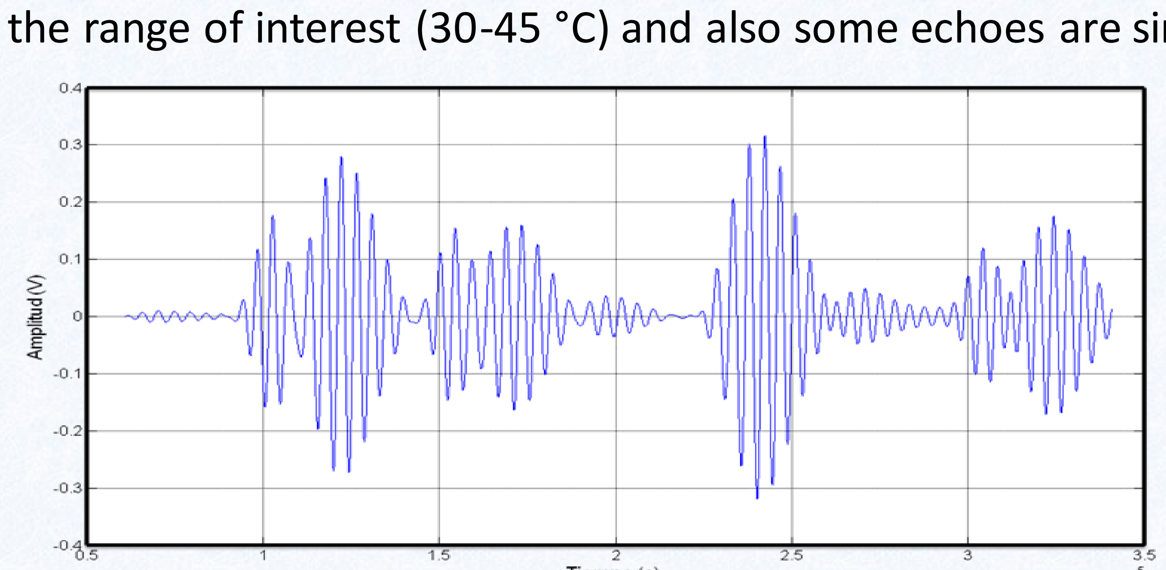
Main aspects of a research to improve the potential resolution of the spectral option

Experimental echo-signals are acquired in a tissue phantom into the range of interest (30-45 °C) and also some echoes are simulated with different levels of noise.





ULTRASONIC TRANSCEIVER [9]



Typical echo from phantoms having scattered internal structure

Overtone	Without Noise	SNR = 3 dB	SNR = 6 dB	SNR = 20 dB	SNR = 40 dB
Frequency	MHz	MHz	MHz	MHz	MHz
4	30.868	30.877	30.874	30.904	30.882
5	39.355	39.410	39.336	39.459	39.424

Spectral responses estimated for several SNR levels (MHz)

Echoes must be PSD processed using digital signal processing techniques proposed for this particular problem [10-11] There is a resonance frequency with overtones, associated with the periodicity of the echoes in a scattered material. The change with temperature in kth harmonic can be evaluated with the expression:

$$\Delta f_k(T) = \Delta T\left[\frac{k}{2d_0}(\beta c_0 - \alpha c_0)\right]$$

[ΔT it is the change of temperature, β the coefficient of change in the ultrasonic speed, α the coefficient of thermal expansion, do the initial mean distance among scatters, and c_0 is the initial speed in the medium].

For PSD estimation of f_k we used spectral options alternatives to the classic operators (Periodogram and Cross-correlation). Parametric procedures of autoregressive type were applied, which are based on the Yule-Walker and the Burg methods [11], achieving a improved high-resolution in temperature (0,12 ºC)

For SNR higher than 3 dB, the *noise influence in the frequency estimation results for high overtones are near to 0.1 %,* which could be neglected in thermal analysis applications.

Conclusions: **High-resolution spectral techniques can be applied to detect pathological thermal alterations indicating important diseases in tissues. An autoregressive parametric procedure can estimate shifts in power spectrum density of ultrasonic echoes overtones, clearly better than with non-parametric techniques. Besides, these options show a good robustness to noise. New efforts must be made with realistic echoes, acquired from real tissues, to confirm the potential resolution of this approach.**

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