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Non-Invasive Ultrasonic Measurements of Small Mechanical Alterations in Sub-millimeter Walls of Arteries and Phantoms

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Abstract

- **To detect alterations in vessels walls, like carotid, is a promising way for early diagnosis of diseases as atherosclerosis, with strong incidence in common causes of mortality. To measure these alterations in a non-invasive way, needs of new researches to achieve accurate estimations of thickness changes in those walls.**
- **Ultrasonic options for spatial measurements in vessel are described; they can be applied in thin walls of arteries and laboratory phantoms, under internal flows. Resolutions improving those derived from images of conventional echography imaging units, could be obtained from multi-pulse echoes.**
- **Some results of applying classic temporal and high-resolution spectral ultrasonic procedures are shown. Their performances are evaluated in a phantom emulating vessel tissues. The distinct responses of processing algorithms, based on cross-correlation and power spectral densities, are commented.**

Introduction

In the medical applications of ultrasound, the research on alterations in vessel walls is a promising work line, in order to investigate an early diagnosis of cardiovascular diseases, such as hypertension and atherosclerosis, with significant changes in the physical properties of the arteries. The major markers indicating atherosclerotic include: thickening, calcification, and stiffness of the wall. Concerning this, the temporal dynamics of the echo-signals must be evaluated in order to dynamically characterize the wall thicknesses.

The use of signals from ultrasonic imaging units with segmentation algorithms [1,2] provides spatial resolution improvements for artery sizing, but the resolutions so obtainable are worse than ≈ 250 µm. These resolution levels are not yet sufficient as to permit thickness evaluation with clinical importance in thin arteries (few microns are needed); the local application of high-frequency ultrasonic pulses is a possible solution in this direction: speckle interferometry with time cross-correlation have been used to measure displacements of walls interfaces.

A non-invasive estimation of these aspects, currently, presents difficulties that must be overcome. In this work, results of applying pulsed ultrasonic procedures, developed by the authors for wall thickness estimation, in sub-millimeter layers of phantoms, are resumed. An improved spectral method is considered, which is based on high-resolution calculation of power spectral densities (PSD) related to the main echoes coming from a wall zone. Two alternative spectral algorithms can be used with good resolutions in order to provide accuracies around the micron.

Some approaches

Some ultrasonic studies were reported, to provide tools more specifically adapted for complementary diagnosis in human vessels, increasing the precision in the analysis of the echo-signals. Examples of it can be seen in [3-5] for changes estimation in thin walls of blood vessels**,** before the arterial disease presents clinical symptoms (atheromas, etc.).
Nevertheless, *to achieve ulterior resolution improvements in arterial walls testing, without excessive complexity in transducers & electronics technologies, requires the generation of new specific techniques in order to locate spatial accuracies around a few microns*. These new solutions for estimating spatial distances would be applicable to facilitate our non-invasive early diagnosis objective. The extension of some recent spectral echo-techniques for precise estimation of changes in the thickness of biological membranes [6] are possible low-cost solutions.

Two estimation options

The echoes can be analyzed with time-defined or parametric spectral methods. *The parametric options have advantages*: high-resolution in frequency and a minor distortion with windowing origin. By a simple time analysis, a spatial pattern of the general wall dynamics can be obtained for successive phantom inflations (Figure 1). But, resulting wall thickness variations cannot be appreciated, due to the scarce spatial resolution of this option. Nevertheless, spectral results from spatial changes in arterial walls, using the overtones changes, can show these variations.

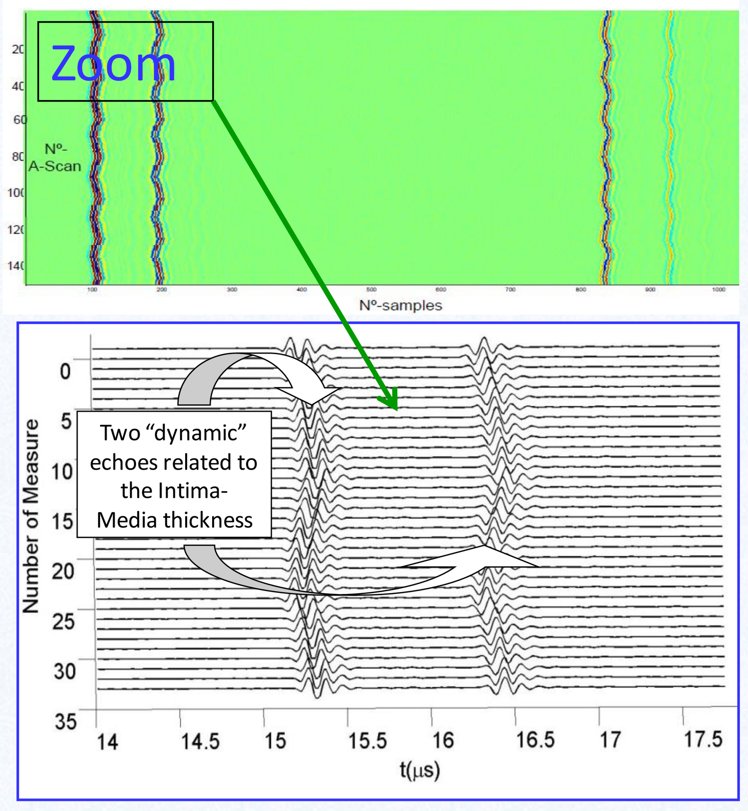

Fig. 1. Time-spatial Changes Display of 35 time-echoes acquired from a wall of an artery phantom filled with water under dynamically changing pressures.

The application of our spectral procedure can detect very-small thickness changes with good resolution. They provide better resolution than classical time-correlation and the basic (non parametric) spectral methods.

<u>Conclusions</u>: A spectral procedure applied in laboratory to estimate shifts in PSD of ultrasonic echoes from an arterial phantom with a 10-MHz transducer shows promising responses to non-invasive estimate small mechanical alterations in thin walls. Good spatial resolution can be potentially attained: of an order of micron, clearly better than with non-parametric techniques or using time cross-correlation techniques For instance, using the 10th overtone, a spatial resolution of ± 0.9 µm was achieved, improving the performance of previous methods using periodogram or pure cross-correlation (around 20-30 µm, ±11 µm in the best case).

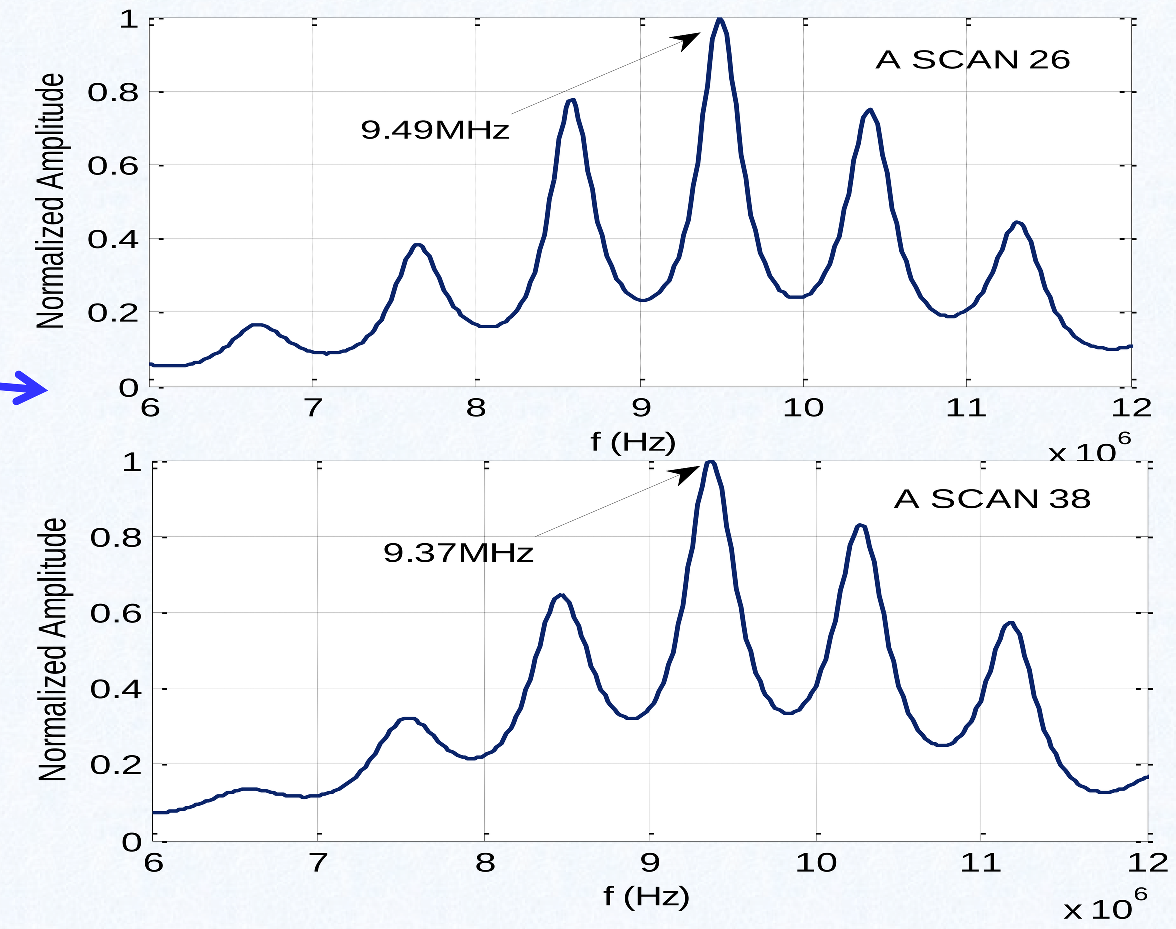

Fig. 2. PSD of experimental echoes, acquired by a 10 MHz transducer at the maximum and minimum inflation levels in an arterial phantom, using the Yule-Walker algorithm.

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