On the possibility to investigate carotid artery plaques with high-resolution imaging system by diffraction of ultrasound.

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ABSTRACT

In this paper a new ultrasound diffraction tomographic image algorithm is presented. A complete laboratory system is built up to test the algorithm in experimental conditions. This tomographic technique only requires two perpendicular scanning sections. On the basis of the presented algorithm two different image formation techniques are investigated.

In the first, an envelope detection of the received signals is adopted. In the second, the radio–frequency signals are directly employed by the reconstruction algorithm. The aim is to investigate the resolution performance with respect to the used wavelength and its spatial dependence. The applications of this method are toward the characterization of the carotid artery disease as the calcified plaques.

Key words : Ultrasonic broadband diffraction tomography, Born approximation, 3–D reconstruction, carotid artery.

1 | INTRODUCTION

Clinical analysis of atherosclerosis demands a quantitative estimation of lesions and stenoses of the carotid vessel and a periodic monitoring of this vessel during the evolution time of the disease.

Ultrasonic techniques have already demonstrated their utility by offering a good characterization of the examined lesions [1],[2],[3],[4]. It is however very difficult to examine the same region with the same parameters at different occasions. Small variations of the view angles and small off sets of the investigated sections change significantly the ultrasonic images.

The 3–D reconstruction of the carotid vessel is a support suitable to find reference sections allowing the physician to supervise the evolution of the disease over a period of time. The 3–D reconstruction may be also a good aid for the difficult determination of the vessel lumen change due to the effect of the calcified plaques or hemorrhagic lesions. Indeed the global aspects of the arterial vessel shape allows a direct evaluation of anomalies. A more accurate analysis is also possible if particular sections from the globally reconstructed vessel can be extracted. Computer based methods can supply 3–D views of the carotid from bidimensional images and the possibility to extract different sections.

A reliable 3–D image can be obtained only from reliable 2–D sections. A previous work [1] of our research group has outlined that also 3–D reconstruction gives poor results for the vessel lumen size determination when the ultrasonic 2–D images are difficulty intelligible. With commercial ultrasonic equipment ten per cent medium errors on phantoms devised by means of an anatomic specimen are observed. The pathological carotid vessel (hemorrhagic or calcified lesions) has a morphology which is not easily detectable by the currently available echographs.

An experimental procedure is proposed. It consists in comparing and relating the results of two investigation techniques obtained with the same scanning and acquisition system:

1)– Straight–path tomography,

2)– Diffraction tomography.

Each of them is based on different physical assumptions leading to different biological tissue approximations. If the biological tissue inhomogeneities have a mean size not greater than the ultrasound wavelength currently used in the clinical equipment, the straight path propagation does not hold. Often the investigated organs are a complex combination of "small" inhomogeneities and reflecting layers, consequently the two techniques give complementary ultrasonic information. The aim of this work is to improve the 2–D

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3) Born approximation [11] is valid, so multiple scattering is neglected and the total field is given by the superposition principle.

The position of a scatterer element placed in the unknown position (x_k,y_K) inside the squared region is retrieved by considering that the observed time of flight (Tof) is given by the equation:

$t^\wedge$ = time of flight of the incident wave corresponding to the distance between the transmitter $(0,y_t)$ and the scatterer element (x_k,y_k),

t_k = time of flight of the scattered wave corresponding to the distance between the scatterer element and the receiver(d,y_r),

The equation (1) defines an ellipse on which the scatterer lies, for each couple of transmitter and receiver positions. Its focal points are in $(0,y_t)$ and (d,y_r).

The amplitude of the received pulse is proportional to the scattering factor f_k located in (x_k,y_k), which is the investigated acoustic parameter for each position of the cross section.

When the data acquisition is completed, all the ellipses can be written in the image matrix with the pixels′ weight equal to f_k. Only in the position (x_k,y_k) the weights are summed coherently so the position and intensity of the unknown scatterer is resolved. The intensity f_k is recovered with a scale factor equal to n^2. When more scatterers exist the above process can be repeated for each one, at least the complete 2D distribution can be represented with an image.

3 | COMPUTER SIMULATIONS AND EXPERIMENTAL RESULT

Computer simulations test the reconstruction algorithm. The scatterers are considered to be isotropic and with negligible size relative to the used wavelengths. The propagation medium is assumed to be without losses. The simulations take into account the real experimental conditions: the front–end hardware characteristics are introduced after a complete set of measurements on the laboratory broadband tomographic system [5]. The proposed diffraction technique considers the transmitter and receiver elements to be isotropic. The transmitter element (f_c=5 MHz, Bw=1.66 MHz at −3dB) is made isotropic by introducing a spherical acoustic lens in the far field probes range; the receiving one is a 10 MHz flat–band hydrophone with an active surface diameter of 0.6 mm. The transmitter/receiver distance (d = 60 mm in Fig. 1) is appropriate to consider the far field approximation valid [9].

The reconstruction algorithm performances are simulated by employing both signals demodulated by analytic signal method and radiofrequency. The aim is to investigate the resolution performance with respect to the used wavelength and its spatial dependence.

For the complete data set method, aliasing is avoided by using a spatial sampling less than $\lambda/4$. The reconstruction based on the signal envelope detection is a less critical method for the spatial and time sampling because the signal maximum frequency is about 0.83 MHz (corresponding to an axial resolution of about 0.9 mm in water). In Fig. 2 a 20X20 mm image of two elementary scatterers is shown. The used time sampling is 50 ns and spatial sampling is 0.3125 mm. The resulting spatial resolution is uniform along the two orthogonal directions and is equal to 0.9 mm at −3 dB.

The reconstruction based on the radiofrequency signals is much more critical in order to preserve the phase information.

In Fig. 3 a radiofrequency reconstruction of a 4.8X4.8 mm image (64X64 pixel) of two scatterers is shown. The adopted time sampling is 12.5 ns and the spatial sampling is 0.075 mm.

An inverse–Wiener filter processing applied to the image shown in Fig. 3 is reported in Fig. 4. The processing exploits the phase information and the resulting resolution is uniform along the two orthogonal directions and equal to 0.115 mm, thus approaching the theoretical limits.

The implemented inverse–Wiener filter has been applyed to the whole image assuming that the system point spread function (P.S.F.) is constant in any image point. When the above assumption is not applicable, differently located scatterers are solved in different ways.

Some trials are in progress to create an adaptive filter which takes into account spatial distribution of the system P.S.F. inside the reconstructed image.

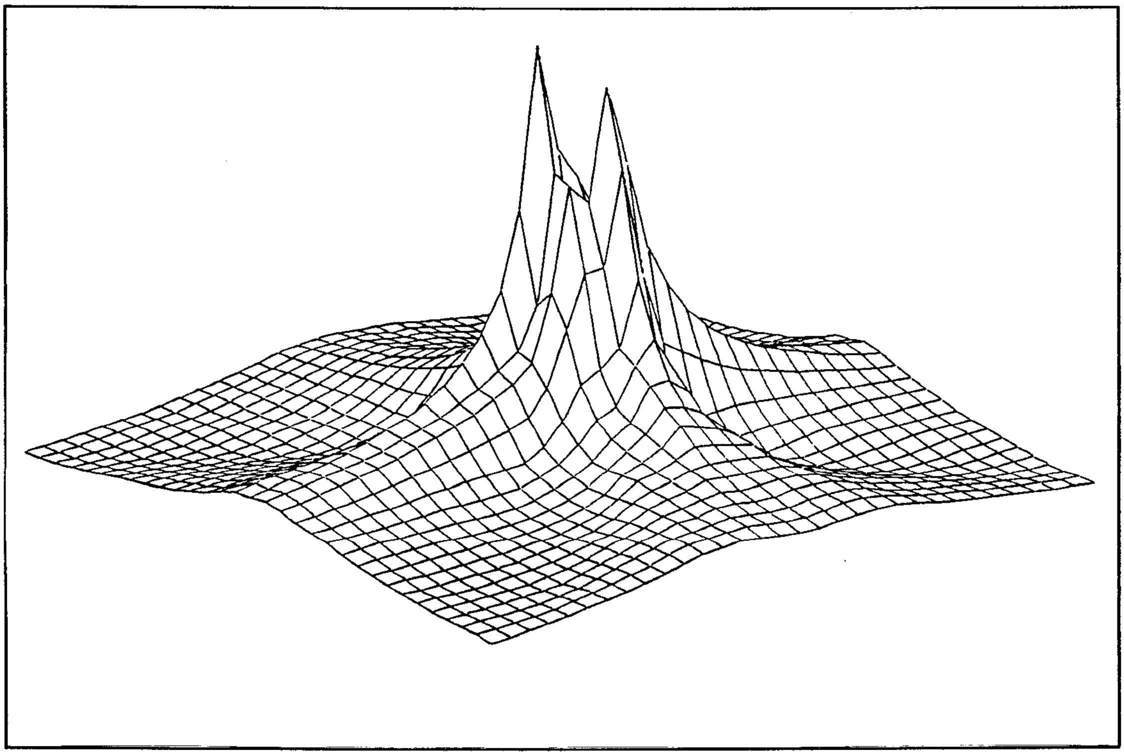

Figure 2 – Envelope detected signal image of two 2 mm distant scatterers.

4 | CONCLUDING REMARKS

The implementation of this laboratory procedure is meant to provide a reference instrument. Images are produced by different investigation techniques: all physical aspects of the ultrasonic–tissue interaction are taken into account. These images supported by the 3–D reconstruction would enable to confirm the ultrasonic capability on the extraction of the lumen size of the carotid artery. In the operative field the image reliability allows a data base of images to be created. The image data base would become a reference support in all ambiguous clinical cases.

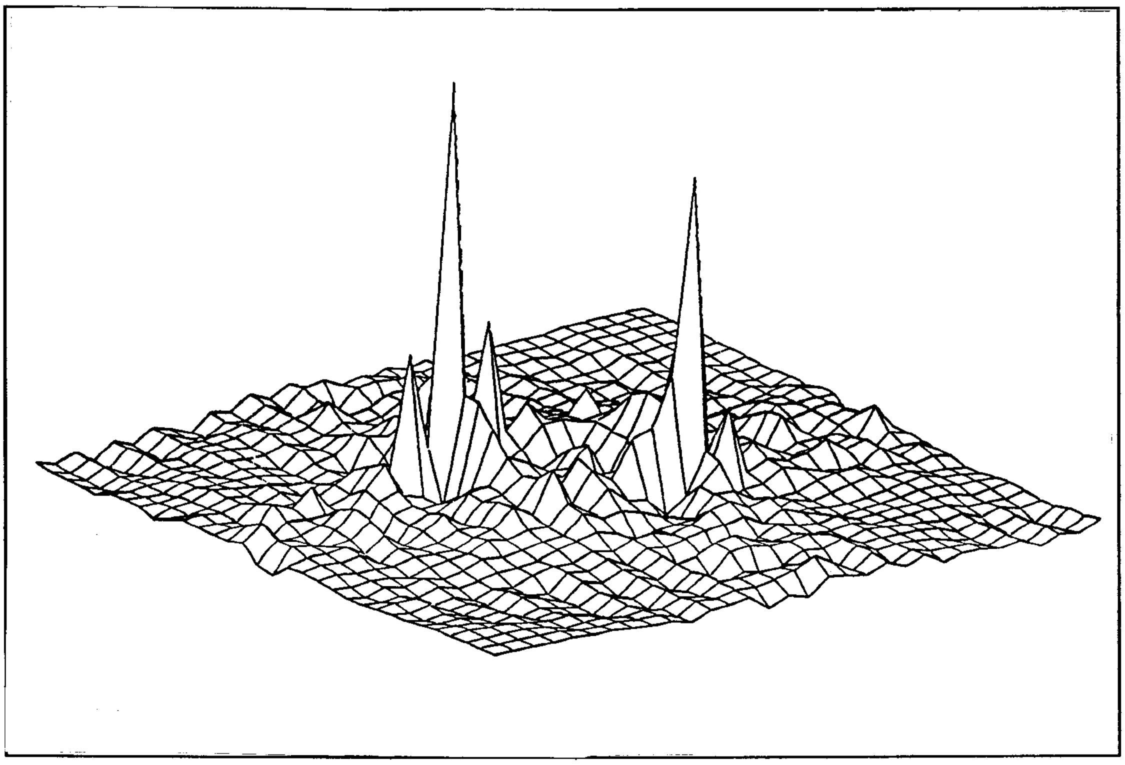

Figure 3 – Radio frequency signal image of two 1.41 mm distant scatterers.

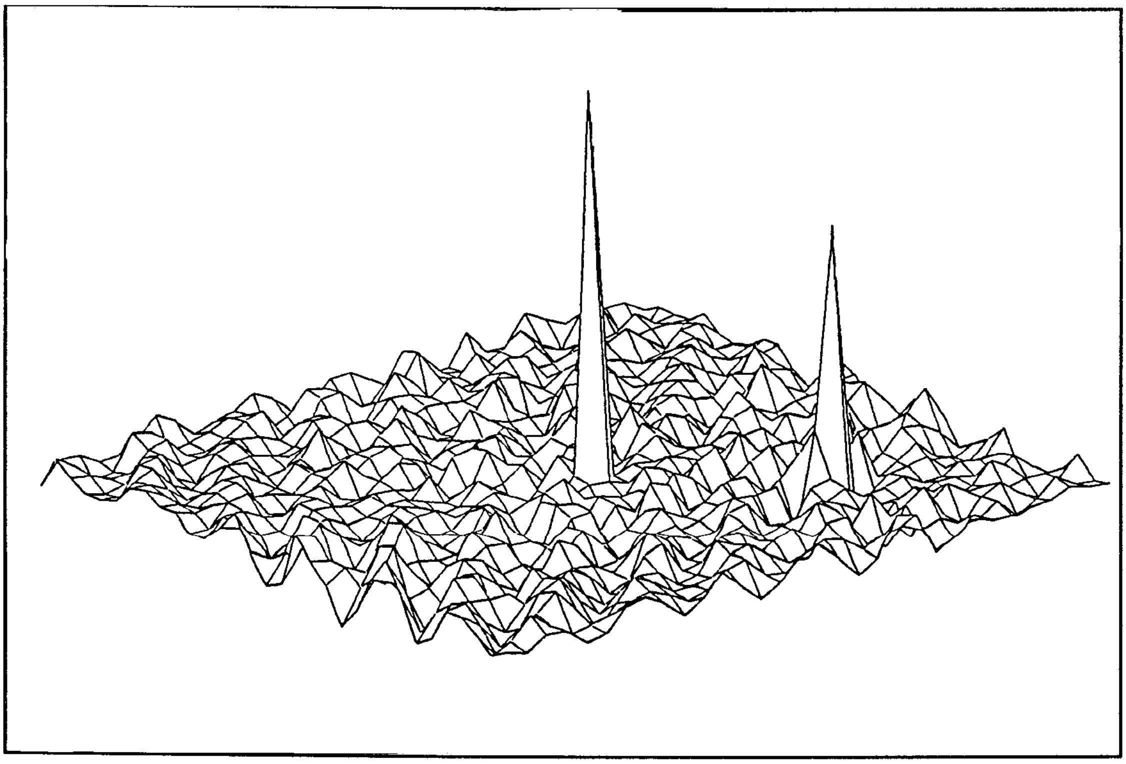

Figure 4 – Wiener filtered image of two 1.41 mm distant scatterers.

6 | REFERENCES

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