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MAXIMUM COHERENCY AS A GUIDE TO OPTIMAL ULTRASOUND IMAGING

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Abstract

Ultrasound signals from conventional imaging machines are an plentiful source of information for describing tissue structure despite bandwidth and aperture limitations. However, a large part of this information content is lost due to electronic processing and limited real time display possibilities**.** Additional processing is possible to extract data about image texture. For image texture parameters and other different tissue parameters, statistical processing methods will be used. Only small part of statistical information can be evaluated by direct human image observation.

Large efforts also have been made to prepare signals, which are not suitable for statistical processing, into a form suitable for human image evaluation. Most of these efforts have been directed towards beam shape improvement. Further efforts have been made towards the reduction of speckle for better recognition of small object in image.

Many ways of improving the signal to noise ratio of ultrasound images are known as compounding. The spatial and frequency compounding are most well known methods for speckle contrast reduction. **If the resolution cell of the ultrasound beam is matched both in position and size to the macro structure of the tissue, then maximum coherency is achieved and the optimum signal to noise ratio results.** In certain situations this improvement of signal to noise ratio is essential. The background theory of maximum coherency in lateral and axial directions of imaging machines will be discussed. Many examples of improvement of signal to noise ratio on special tissue mimicking phantoms will be shown.

Theory

With some quality control phantoms, under certain conditions it is possible to observe strong coherent echoes on the edge of the scattering volume (Fig. 1). This phenomenon is experimentally examined using special phantoms and supported with simple simulations. The general conditions for the generation of coherent echoes are investigated.

The ultrasound backscattering signal is the convolution of the scatterer density function ‘h‘ and the insonating ultrasound beam function ‘t’.

$$\mathbf{i(\xi,\eta,\zeta) = \int_V h(x,y,z)\ t(\xi-x, \eta-y, \zeta-z)\, d\xi d\eta d\zeta} \quad (1)$$

t (x,y,z) is a band limited function with no DC component in the z direction. Constant sound velocity and zero attenuation are assumed.

Newhouse shows that if the gradient of h (x,y,z) is equal zero, then $i(\xi,\eta,\zeta)$ also zero. The expression (1) can be written in the frequency domain to give:

$$\mathbf{I(\omega_x,\omega_y,\omega_z) = H(\omega_x,\omega_y,\omega_z)\ T(\omega_x,\omega_y,\omega_z)} \quad (2)$$

The condition:

$$\mathbf{t\ (x, y, z) = k.\ h(\xi_o-x, \eta_o-y, \zeta_o-z)} \quad (3)$$

or

$$\mathbf{T(\omega_x,\omega_y,\omega_z) = k.\ H^{*}(\omega_x,\omega_y,\omega_z)\ exp[-i(\omega_x\ \xi_o\ ,\ \omega_y\ \eta_o\ ,\ \omega_z,\ \zeta_o\ )]} \quad (4)$$

must be fulfilled if the maximum response of the system at the point ξ_o, η_o, ζ_o have to be achieved. This means that the maximum system response is achieved if the scattered density function has an identical form to the insonating function with time inverse. This is known as the matched-filter principle and corresponds to the autocorrelation concept. Practically it means: If the resolution cell of the ultrasound beam is “matched‘ in position and size to the insonated “object“ then the maximum response will be achieved. All other structures with equal values of density gradients will give a lower level response. At the extremes, the zero response is also possible and this is the origin of the well known speckle pattern.

The presented theory shows that the backscattering is dependent on scatterer space distribution as well as the insonating beam shape and the bandwidth of ultrasound imaging system.

The probability of complete matching between the insonating space wavelet shape and tissue structure in all directions is very low. Mainly only a partial matching will be achieved. Great potential possibilities for recognition of different tissue structure would exist if the insonating wavelet shape could be matched to known tissue structure. Simultaneous interrogation and recognition of tissue, containing different types of tissue structures, seems to be feasible, or at least imaginable, even with die limited bandwidth. A color display would be used.

Results

Before the results from phantom will be presented, let show some simple simulation. The next image (Fig. 2) shows a simulated l-dimensional density function of convolution with the band limited wavelet. The matching response to the burst is obvious.

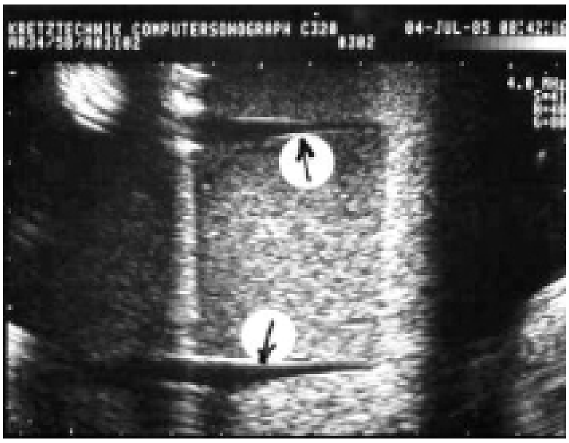

Fig.1.

The next image (Fig.3) shows a simulation of random density function with its power spectrum in the second line und its band limited power spectrum in the third line. The last line shows die resulting convolution of the random density function with the transmitted wavelet. Partial matching causes the series of bursts, which can be seen in the last line.

The next images **(Fig.4-5)** present the r.f. response of two scattering volumes between the entry and exit echoes. Each volume has same average scatterer density but different scatterer distribution. Contribution of non-homogeneity to backscattering can thus be substantial.

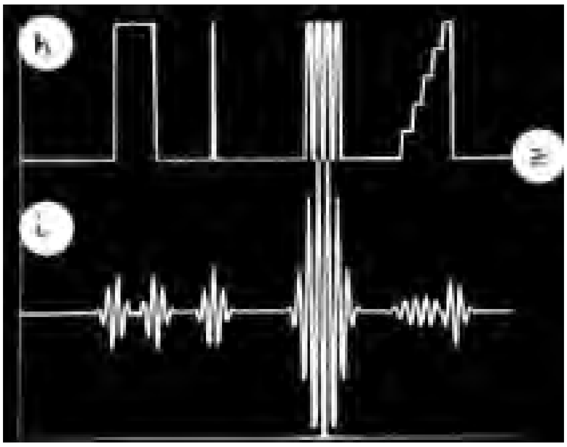
Fig.2.

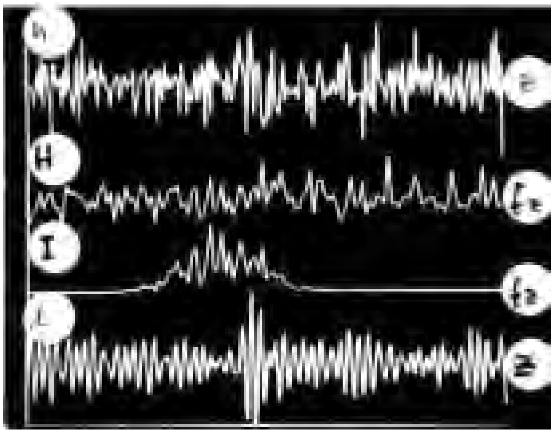
Fig.3.

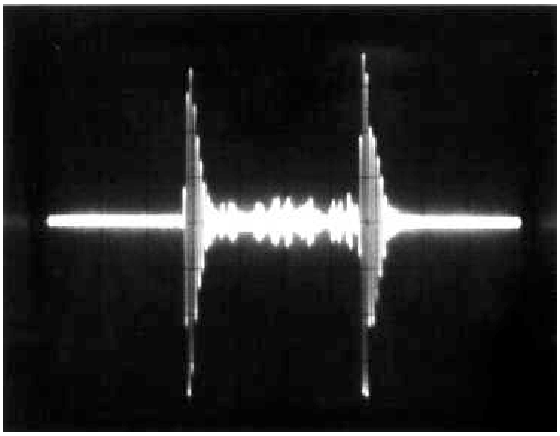
Fig.4.

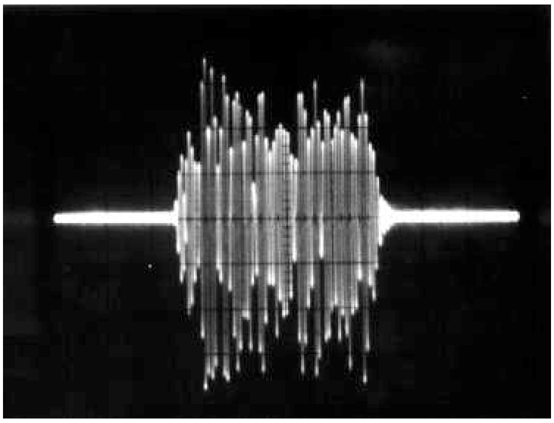
Fig. 5.

The next images (Fig.6-7) show two B-scans, perpendicular to each other, of the special phantom. The thin tube, see arrow, mimics the “ductus pancreaticus“ und can be seen in the longitudinal scan, but in cross section it is obscured by the speckle pattern. If the slice thickness of the B-scan is substantially increased, then matching takes place in the transverse plane as can be clearly seen in the next images (Fig. 8-9).

The next images **(Fig**. 10-11) show the accentuated boundaries of the same tube caused by gratings lobes of a linear array. This artefact is also an effect of partial matching in the convolution process**.**

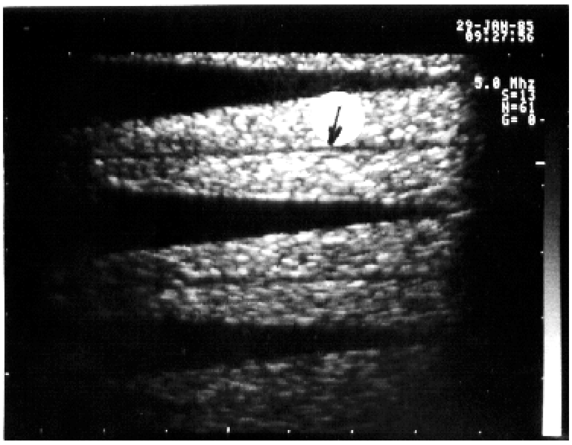

Fig. 6.

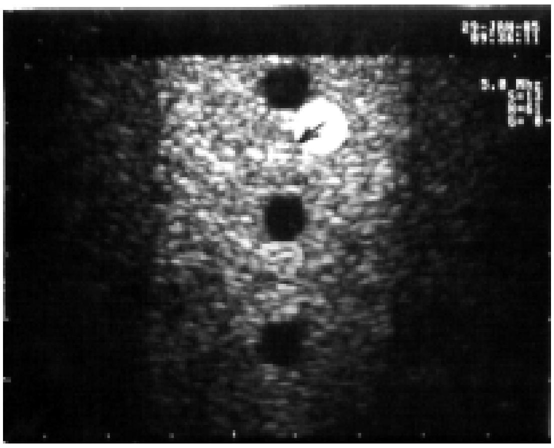

Fig. 7.

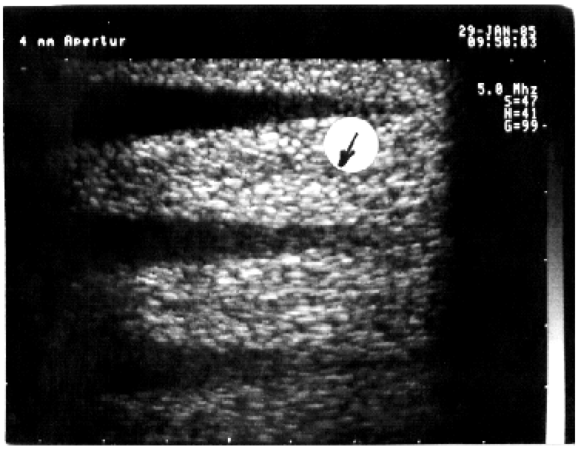

Fig. 8.

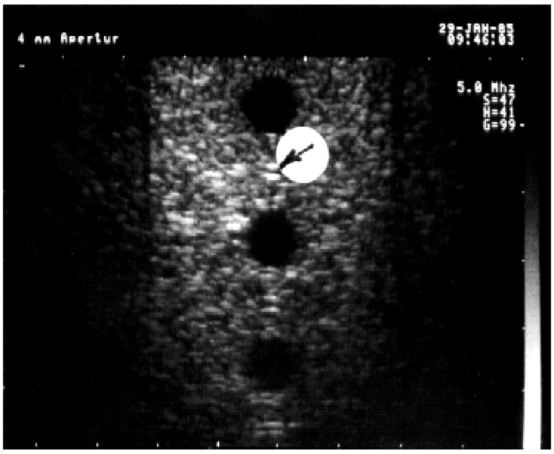

Fig. 9.

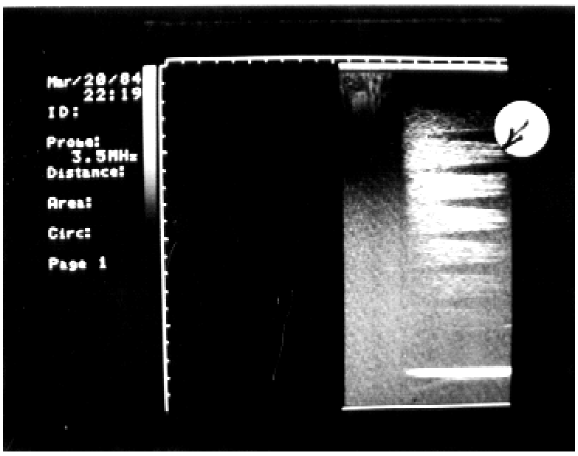

Fig. 10.

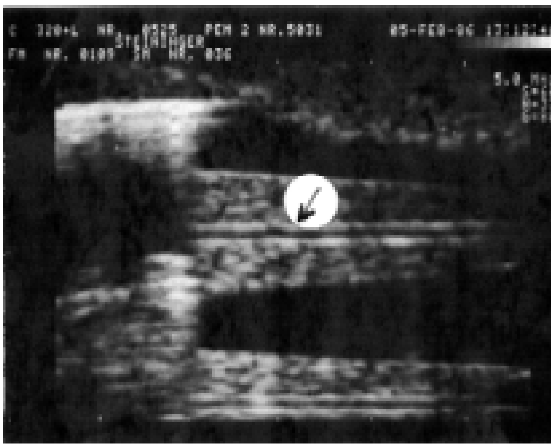

Fig. 11.

Next images (Fig. 12-13) show the B-scans of the tissue mimicking phantom using full und reduced bandwidth. The generation of matched bursts with reduced bandwidth is evident.

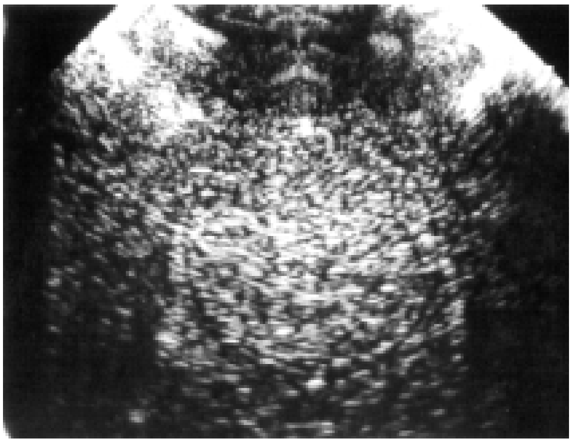

Fig. 12.

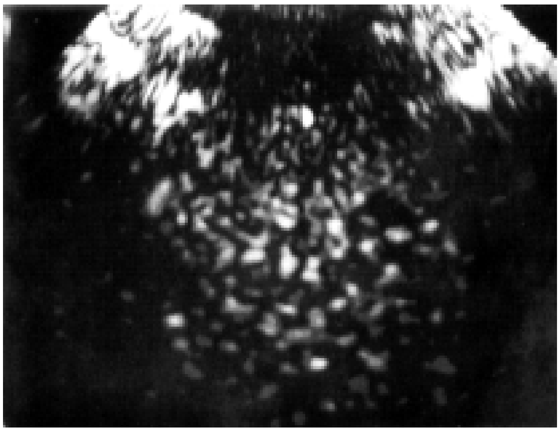

Fig. 13.