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SPECTROSCOPIC ULTRASONIC COMPUTER ASSISTED TOMOGRAPHY - A PILOT STUDY

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The ultrasonic equivalent of the X-ray computer assisted tomography system was first implemented and developed by GREENLEAF and his colleagues (1,2). Of the ultrasonic imaging systems presently available, computer assisted tomography has the peculiar potential of providing images which are, to a first approximation, maps of the gross propagation parameters that are generally considered to be fundamental - speed and attenuation. It is a transmission method of imaging, the 'velocity' maps being reconstructed from the propagation delay and the 'attenuation' maps from the amplitude of the signal transmitted. The main applications to date appear to have been in breast scanning (3).

It appears that short (broadband) pulses are almost exclusively used. Particular problems arise in the reconstruction of time delays (4) due to the fact that the very inhomogeneities that are of interest cause deviation of a given ray from the straight line joining source and receiver that is usually assumed in the reconstructions. In addition the pulse amplitude reconstructions may be affected by inhomogeneities disturbing the integrity of the wavefronts (5) and by reverberation effects if long pulses are used. The work reported here was commenced to investigate several further areas of uncertainty that appear to remain. The first of these arises from the fact that the criteria for measurement of the time delay and amplitude are, for a short pulse, rather arbitrary. This problem is enhanced by the complexity of the field radiated by a finite, transient-excited source (6). The second concerns the question of the optimum choice of transducer, including specification of the measurement procedure that should be used to define the emission and reception characteristics. The choice of transducer is closely related both to the structure of the medium under investigation and to the reconstruction algorithms to be used. It was hoped that it might be possible to work towards the important practical numerical compromise between the spatial resolution and the sublety of parameter differentiation achievable in the map of a given material.

In the first instance, on relatively well-behaved materials, it is possible, we believe, both to remove a large proportion of the arbitrary choice of criteria mentioned above, and to make full use of the relatively time consuming process of data collection, by a spectroscopic approach to the analysis of data prior to reconstruction. We have shown previously (7) the possibility of obtaining the variation of both the attenuation and the phase velocity over a reasonably wide bandwidth by simple analysis of, respectively, the amplitude and the phase of the Fourier transform of a broad band pulse traversing a sample of homogeneous material. The elementary data input to the computer for subsequent reconstruction is essentially the same as that for simple measurements of attenuation and velocity and has the same attendant problems of interpretation (8). (Within the limitations imposed by these problems almost all the conventional measurement methods can be used to obtain input data, with the trivial qualification that the methods cannot involve varying the path length in the material.)

The equipment used is shown schematically in Figure 1. In order to maintain the integrity of the spectral components that was required and to enhance the signal to noise ratio of weak signals a boxcar system (9) was employed to record the transmitted pulse for each step of the stepping motors (x_i,θ_i). A purpose-built stepping motor controller permitted manual operation or automatic (computer-controlled) manipulation of the motors. In the automatic mode, the motors were successively stepped through the x_i for each θ_i and through the θ_i. For the system implemented, two practical limitations arose.

Taking 512 samples over 50μs for the pulses transmitted, permitted only approximately 1600 pulses to be stored per disc. Thus although the stepping motors permitted movements of 7.5μm and 0.01π radians, the steps planned gave readings every 9 degrees and 1mm (over 4cm). The second constraint arose from the time taken for the boxcar to scan each pulse (approximately 50 sec). To avoid excessive run times the data was taken with coarse translational sampling (4mm) in several runs with initial relative displacements of 1,3mm, and subsequently mixed.

Initial trials have been performed on the pulse data in the time domain using a search programme which selects features of the pulse, such as the time delay before the leading edge of the pulse achieves a preset multiple of the noise level, or the amplitude of the maximum positive peak in the pulse. The target used and two typical reconstructions are shown in figure 2 and show the main features expected but clearly suffer from inadequate sampling. The reconstruction was performed using the convolution reconstruction procedure from SNARK 75(10) run on the CDC6600 machine at ULCC.

The search for optimum transducer beam shapes led to the investigation of suitable collimating systems. The hollow tubes (11,22) which have been suggested in the literature have some advantages although a wider-ranging systematic investigation in the present context appeared necessary. It was found that masking of the transmitter with rubber collimators (approximately 5mm thick) with different sized (circular) holes mounted axially produced approximately the same major beam characteristics as would be expected from a simple limitation of aperture. The beams were assessed as peak amplitude profiles plotted using a small detector of approximately 1mm diameter. Similar aperture restriction of the received beam produced rather curious results in that the insertion of the aperture remote (10-20cm) from the transmitter (1.5cm nominal diameter) appeared to produce not only a marked narrowing of the beam, but also an increase in the peak pressure in the beam by as much as a factor of three. The maximum peak was not always observed immediately adjacent to the exit of the aperture. Figure 3 shows typical results. More comprehensive results are given in (13) and while the wavefront geometry may affect the amplitude of the signal recorded it is believed by the authors that this effect is reproducible. A more precise investigation is clearly needed although this will be limited by the difficulty of precise machining of good ultrasonic absorbers. Care must also be taken at low apertures where the energy transmitted through the absorber is comparable with that transmitted by the aperture.

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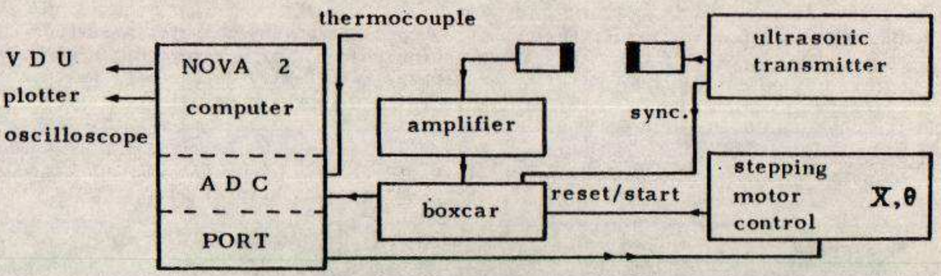

Figure 1 : Schematic diagram of computer assisted tomography system

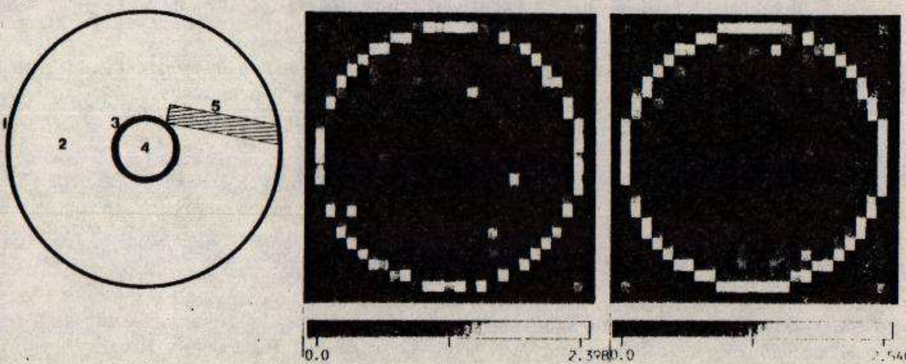

Figure 2 : (a) Object; (b) delay and (c) amplitude density reconstructions.

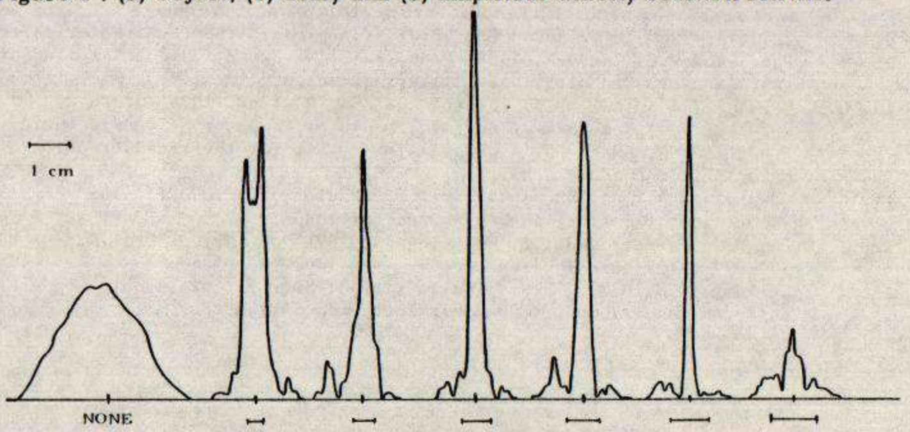

Figure 3 : Variation of pressure amplitude across the exit of a rubber aperture 15cm from a 1.5cm diameter, '1MHz' transmitter.

The studies reported suggest that spectroscopic ultrasonic computer assisted tomography is possible, but that a considerable amount of development is needed before its potential and limitations can be scientifically defined. The majority of the points of uncertainty are related to the physical acoustics of inhomogeneous media.

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