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QUANTITATIVE IMAGE INDICES IN ULTRASONIC DIAGNOSTICS OF INHOMOGENEOUS MATERIALS

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The use of a commercial image analyser for dimensional analysis of discrete features of ultrasonic images has been described previously. The present paper reports a pilot study on the use of such an analyser for quantitative analysis of the diffuse texture of an ultrasonic image of an inhomogeneous material. Althought such a use may provide valuable arbitrary diagnostic indices, a procedure is outlined by which such indices may be used in conjunction with visual perceptual studies to optimise the display or to investigate the physical mechanisms of image formation.

1. Introduction

The use of an image analyser for obtaining quantitative information on the dimensions of discrete structures in ultrasonic *B*-scan pictures has been described previously [1]. As was indicated in that communication, the use of such an analyser may be extended to the derivation of quantitative information which is related to the visual texture of ultrasonic grey-scale scans of inhomogeneous materials. This paper reports a pilot study of such an application. The discussion is couched in terms which are directly related to the problems of medical diagnostics. This is a reflection both of the fact that the original stimulus to the investigation was a medical problem, and also of the fact that medical diagnostic techniques for inhomogeneous materials have developed rather faster than their counterparts in industrial applications. It should therefore be borne in mind throughout the paper that the discussion could equally well apply to the ultrasonic diagnostics of other inhomogeneous systems such as concrete, sediments, metal inclusions, etc.

The first quantitative approach to the diagnostics of inhomogeneous material appears to be that of Denier in 1946 [2], who reported on the basis of a one-dimensional *A*-scan, an excess of echoes from cancerous tissue compared to normal tissue. The first qualitative use of texture in *B*-scans (two dimensional tomograms) appears to be that of Howry whose brief atlas of diagnostic ultrasonic results published in 1965 [3], proved a model which has only in relatively recent years been superseded. The technological developments that have made possible the display of a very wide range of echo amplitudes in grey-scale imaging [4, 5] have permitted the textural analysis suggested by Howry to be performed, to some extent, by almost any operator. The technological development of Kossoff and his workers was accompanied by the development of quantitative methods of tissue characterization [6-9]. The circumstantial evidence which supported these developments has been previously collated [8-10] while the current status of ultrasonic tissue characterization has been comprehensively reviewed very recently [11], and some of the fundamental difficulties with these approaches outlined [12].

The essential problems of these quantitative methods are the relatively poor current definition of the ultrasonic beam radiated into water, the rudimentary level of understanding of the way in which tissues whose gross acoustical properties are known will affect the beam pattern, and the essential difficulty of relating this information to the in vivo situation, where the content, structure and properties of the tissues lying between the skin and the region which has been selected for analysis are unknown in detail.

One of the methods of tissue characterization which involves these problems only in an indirect way is a simple analysis of the echo patterns actually displayed on the *B*-scan. This paper discusses some of the elements of such analyses. It reports novel measurements in which the area of interest may be sampled by a light pen for subsequent microprocessor analysis and outlines the conditions under which such a method may be used for empirical tissue characterization. Finally a procedure is suggested by which this method may be used to discover the relative importance of different factors in the process of image formation, and two approaches to the optimization of the ultrasonic visualization of inhomogeneous materials, by any of the visualization techniques available at the present time.

2. Methods of analysis

It is implicit in image formation and display that each of stages in the process from the generation of the initial electrical signal to the final display of the image will introduce some limitation on the extent or the significance of the analysis of the image that can be performed. In turn the method of analysis will have its own limitation and, of course, the most restraining limit in the chain is the one that is effectively operative.

Two main methods of analysis are available: analogue (optical) techniques and digital (computational) techniques. The computational techniques devised primarily for microscopic analysis [13] are impressive both in range and sophistication. They have undoubted advantages in the problems that involve spatial (dimensional) information, including area on a point by point basis. Additionally they offer memory for the storage of results, and a light pen facility for the convenient selection and display of an area of interest.

By comparison, optical techniques must be considered limited, cumbersome and difficult in the area of spatial (dimensional) analysis, but they have particular potential in the analysis of spatial frequency distributions. With relatively simple apparatus, [14], they can rapidly provide a (spatially) continuous transformation of the information in the original picture. In turn this transformation may be masked and retransformed to obtain a spatially filtered version of the original image. Whether or not this is appropriate for the images that exist, or that may exist, as ultrasonic images of inhomogeneous systems, remains to be investigated. The major disadvantages of this approach tend to be the relative inflexibility of the shape of the area that can be selected for analysis, and the fact that the result of the transformation remains, in the first instance, another unquantified image requiring subjective assessment.

The change of image may nevertheless be extremely useful as can be seen from the examples shown in an optical transform atlas [15], and optical image analysis is certainly worthy of investigation, in spite of the photographic problems mentioned in section 4. However, the present author has pursued the computational techniques, both for the potential ease of implementation in a clinical situation, and also because of their importance in the logical development towards optimization of instrumentation (section 5).

3. Experimental material and methods

The pictures upon which the analyses were performed were taken during routine examinations with a commercial compound grey-scale scanner. They were recorded on 70 mm roll film (as negatives) and since the work reported here was not conceived when they were taken, no constraints were placed on the gain, brightness, exposure or development settings to make them particularly suitable for this analysis. Matt prints (on resin coated paper) were made from the negatives using automatic timing and developing systems, and the analyses were performed under identical illumination and magnification of the prints.

The analysis was performed on the commercially available image analyser previously described [1] (Quantimet Model 720*M*, Cambridge Instruments, Royston, Herts, U.K.). A light pen was used to select an area of interest on the television display of the image of the print. The area of the selected region was measured, in terms of the number of picture points (there are 60400 points in the whole 720 line display), and the setting of the scaled "grey-level" control on the analyser gradually reduced. This "grey-level" control effectively changes

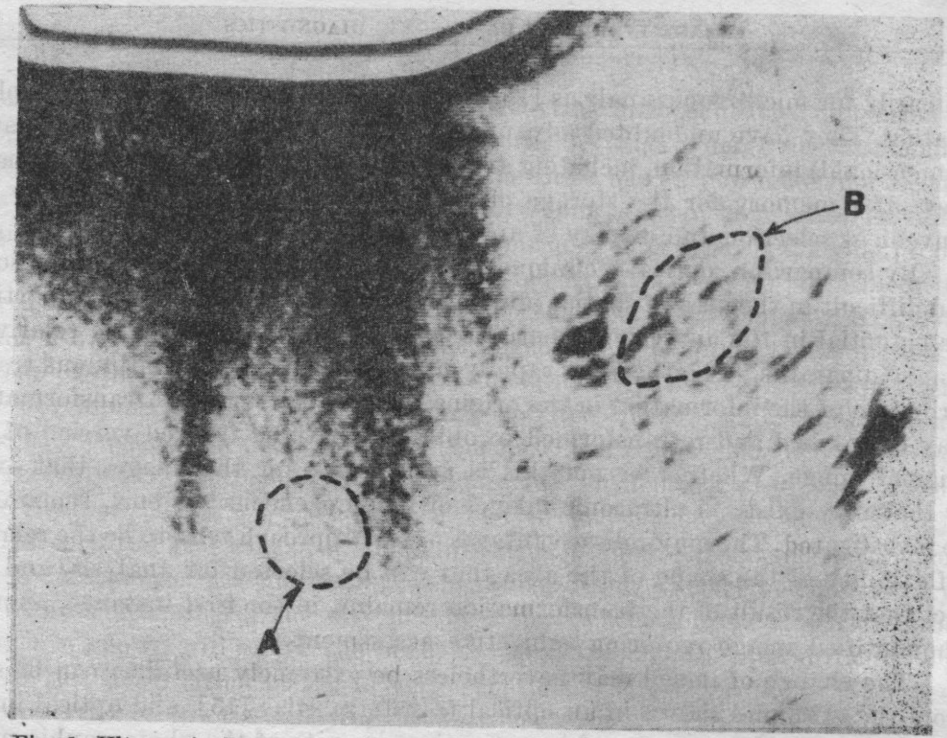

Fig. 1. Ultrasonic *B*-scan, number 1, with the regions *A*, *B*, selected for analysis

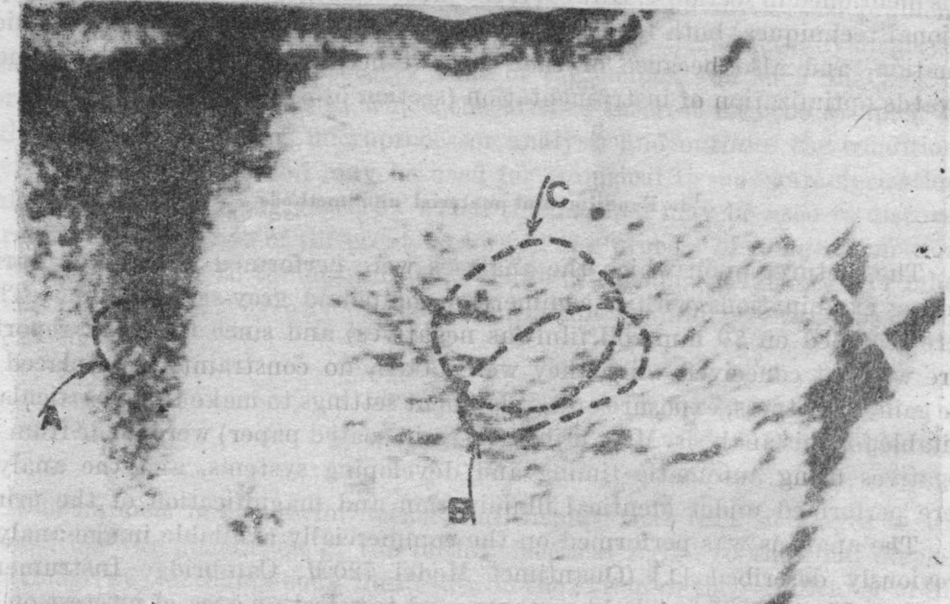

Fig. 2. Ultrasonic *B*-scan, number 2, with the regions *A*, *B*, *C* selected for analysis

the threshold of brightness in the image that is required before a point will register and be displayed on the television monitor. One of the facilities of the analyser is an automatic readout of the area (within the region selected with the light pen). Thus as the setting of the grey-level control is reduced, it is possible to determine the percentage of the area of the selected region which is above a certain brightness. This is the analysis that was performed in this work. The grey level scale is an arbitrary one: a level of 55 corresponds to a threshold at which all the points in the selected region register (i.e. it represents darkness), and while measurable areas remained below a grey level of 10 none of the images had areas below a grey level of 8.

Three original scans which were analysed are shown in Figs. 1-3, the approximate regions selected for analysis being outlined and labelled with letters. The numbers 1-3 are used as original scan indices. Table 1 shows the areas of the selected regions in terms of the number of analyser picture points contained. (The limit of resolution is 4 picture points). The regions were selected for different reasons. Regions 1*A* and 1*B* are clearly different from a visual point of view, as is region 2*A* from regions 2*B* and 2*C*. The difference, visually, between regions 2*B* and 2*C* is relatively small, although the latter appears to have rather more white space in it. Similarly 3*A*, 3*B* and 3*C* are visually distinct

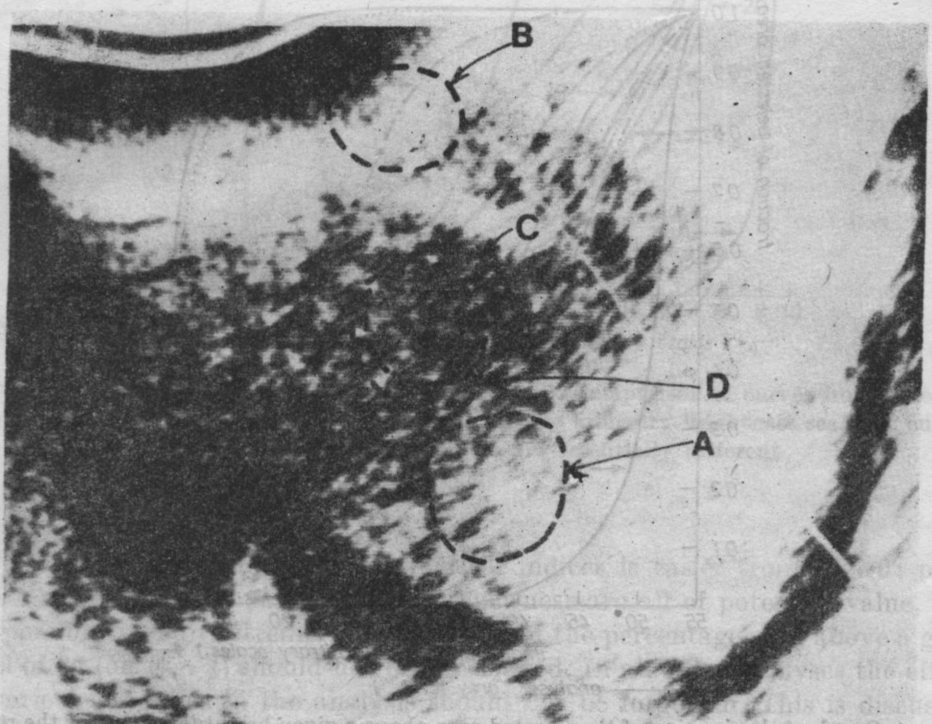

Fig. 3. Ultrasonic *B*-scan, number 3, with the regions *A, B, C, D* selected for analysis

from each other and from 1*A*, 1*B*, 2*A*, 2*B* and 2*C* but are closest to the last two. Finally 3*D* was an attempt to assess the reproducibility of 3*C*.

The results of the analyses are shown in Fig. 4 for all these selected regions of three original scans. The lack of control of the photographic and display parameters in obtaining the original scans (Figs. 1-3) implies that the arbitrary brightness scales used for analysing the individual scan pictures differ essentially from each other. It means that these scales for selected regions labelled with different numbers cannot be compared to each other. This must be borne in mind when interpreting Figs. 4-6 in which the curves from all three scans have been superimposed for illustrative purposes. The immediate impression is that the index chosen (i.e. the way in which the regional images have been quantified) is one which accords well with the visual (subjective) analysis. Fig. 5 shows Fig. 4 plotted with a logarithmic grey scale. As may

Table 1. Relative areas of selected regions (in analyser picture points)

Region	Area (picture points)
1*A*	5352
1*B*	9820
2*A*	3204
2*B*	12740
2*C*	16220
3*A*	18234
3*B*	15400
3*C*	18508
3*D*	17164

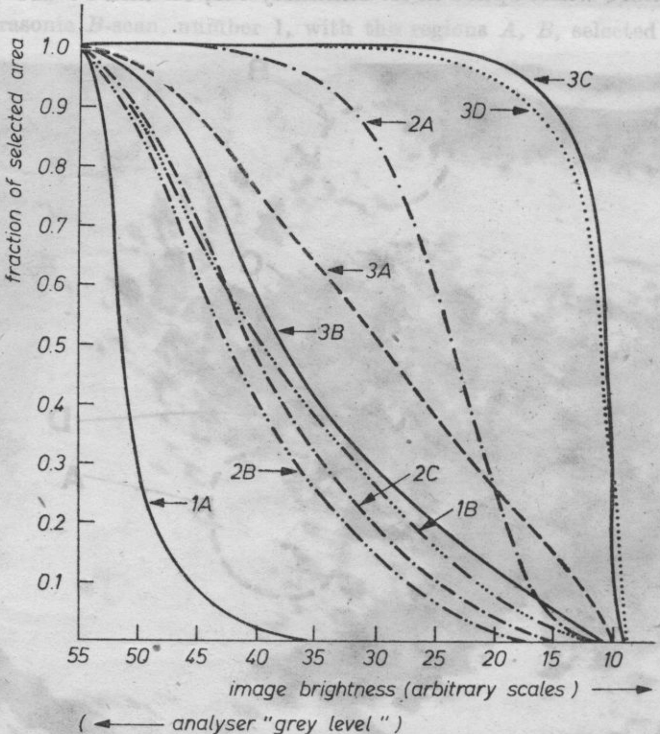

Fig. 4. Graph of the fraction of the selected area above a given brightness level for the regions marked in Figs. 2, 3. The brightness scales are arbitrary and different for curves from different scans (i.e. labelled with different numbers)

be expected the general results are qualitatively similar as far as discrimination is concerned, although Fig. 4 appears to be more reliable. Fig. 6 shows the gradients (first derivatives) of the curves in Fig. 4. These gradients can only be regarded as approximate, since they have been sketched by manual methods (by plotting the gradient of the chord between adjacent data points in Fig. 4 at the mid point of their abscissae). This form of display has obvious advantages for differentiation, although the possibility of points at which curves cross (see Fig. 4, *1B*, *2C*) coinciding with the points of inflexion, and the potential similarity of curves *3B* and *2C*, implies that both types of display (Figs. 4 and 5) should be used in the first instance.

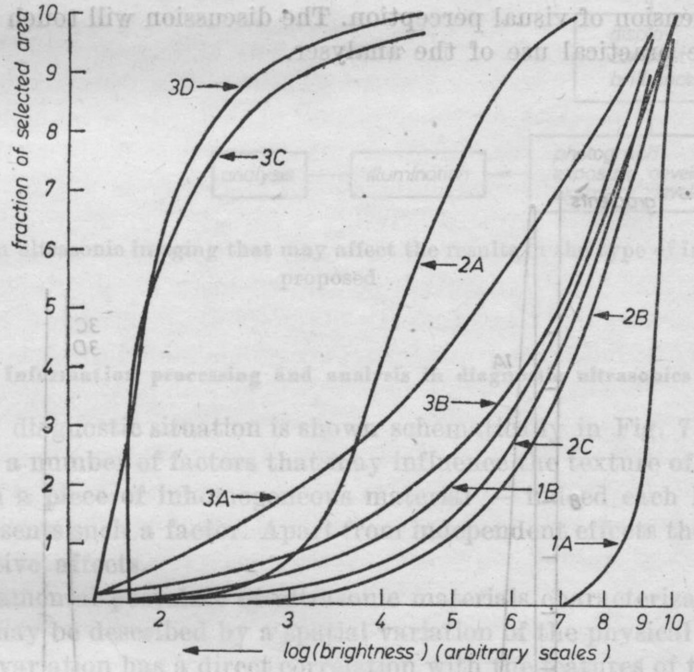

Fig. 5. Fig. 4 with a logarithmic brightness axis. N. B. Comparison of curves from different scans (i.e. Figs. 1-3) can only be illustrative, since the arbitrary brightness scales of curves labelled with different numbers are essentially different

Certainly the extraction of numerical indices is easier from Fig. 6: peak position, peak height, peak width and skewness are all of potential value, but the possibility of an extremely simple index of the percentage area above a grey level of 30 (on Fig. 4) should not be overlooked. In all these analyses the effect of various processes in the analysis should not be forgotten. This is discussed further in the next section, but it is relevant to suggest that the effect of over or under exposure in the photographic processes, or of changing the analyser illumination, could change curve *2C* into curve *3B* (or vice versa) if the system is linear, or simply to change the shape of the curve if it is not. This would not only affect the simple index of the percentage area above a brightness level of, say, 30 mentioned above, but also shift the peaks of Fig. 6 (or if nonlinearity is present, change their amplitude).

The method of analysis chosen for these experiments was the simplest available, and the range of potential analyses and indices is great. There are severe qualifications on the apparently successful pilot study reported, and the particular procedures used. The remainder of the article is thus devoted to a discussion of the circumstances under which the analyser, with its inflexible numerical regimentation may be more usefully employed than the subtle adaptive comprehension of visual perception. The discussion will touch on the limitations of the practical use of the analyser.

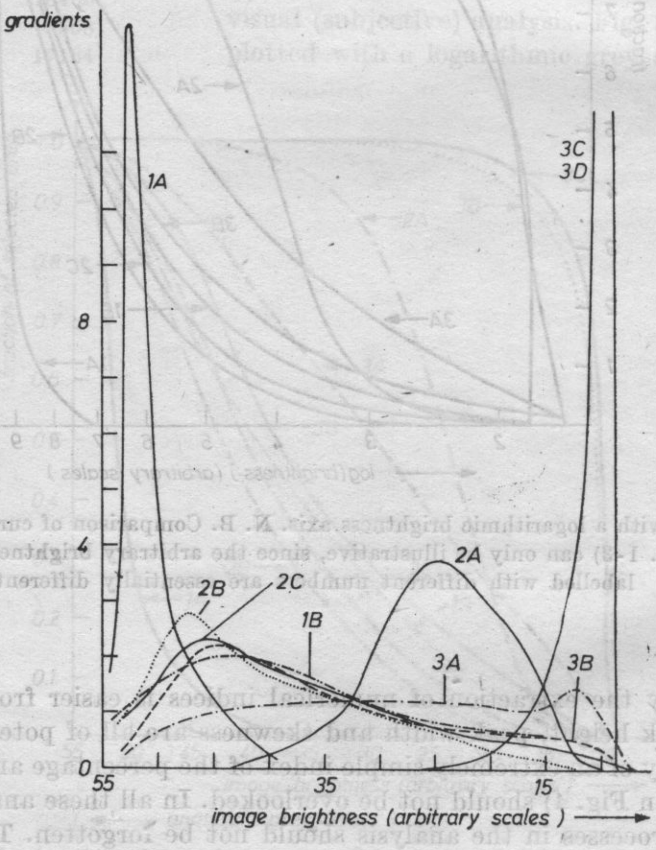

Fig. 6. The gradients (first derivative) of the curves of Fig. 4 plotted against brightness. N. B. See note on Fig. 5

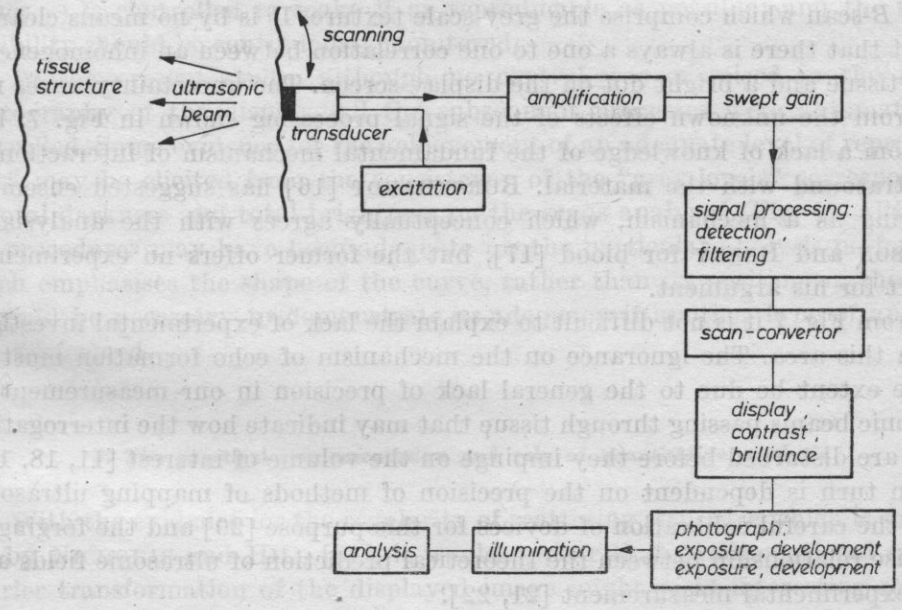

Fig. 7. Factors in ultrasonic imaging that may affect the results in the type of image analysis proposed

4. Information processing and analysis in diagnostic ultrasonics

A typical diagnostic situation is shown schematically in Fig. 7. It is clear that there are a number of factors that may influence the texture of the picture obtained from a piece of inhomogeneous material — indeed each label in the diagram represents such a factor. Apart from independent effects they may also have cooperative affects.

The fundamental postulate of ultrasonic materials characterization is that the material may be described by a spatial variation of the physical parameters and that this variation has a direct correlation with the features of the material that are of interest to the diagnostician, e.g., strength for composite materials; type and condition for human tissues. The parameters that are considered relevant for the propagation of ultrasound are the velocity of propagation, the density, and the bulk modulus (or the elastic constants for a crystalline material). Opinion is divided about the relative significance of these and the linear scale of their variation in human tissue largely, the present author believes [11], because of a shortage of reliable data.

The traditional mechanism suggested for the production of the diffuse echo pattern under discussion is a scattering process [8-11], although the identity of the inhomogeneities that give rise to the scattering is, certainly in tissue, unclear at present. We may refer to "scattering centres" as points from which the scattered waves appear to emanate (sources) to produce the bright dots on the *B*-scan which comprise the grey-scale texture. It is by no means clear at present that there is always a one to one correlation between an inhomogeneity in the tissue and a bright dot on the display screen. The uncertainty arises not only from the unknown effects of the signal processing shown in Fig. 7, but also from a lack of knowledge of the fundamental mechanism of interaction of the ultrasound with the material. BURCKHARDT [16] has suggested ensemble scattering as a mechanism, which conceptually agrees with the analysis of ATKINSON and BERRY for blood [17], but the former offers no experimental support for his argument.

From Fig. 7 it is not difficult to explain the lack of experimental investigation in this area. The ignorance on the mechanism of echo formation must to a large extent be due to the general lack of precision in our measurement of ultrasonic beams passing through tissue that may indicate how the interrogating waves are disturbed before they impinge on the volume of interest [11, 18, 19]. This in turn is dependent on the precision of methods of mapping ultrasonic fields, the careful calibration of devices for this purpose [20] and the forging of a precise relationship between the theoretical prediction of ultrasonic fields and their experimental measurement [21, 22].

There is almost no doubt that the field emitted by a transducer will, in some way, influence the signals that present themselves for subsequent visualization. To date only GORE and LEEMAN [23], following Atkinson and Berry [17], appear to have included some measure of accommodation for this in their theoretical development. They use a "beam profile" but with no indication as to where or how it may be measured.

The scanning regime is of particular importance. The storage of superimposed (compound) scans may produce degradation of the visual information due to uneven scanning with a hand-held scanner or due to angular scattering effects. Real-time scanners obviously overcome these problems at source, whether mechanically or electronically scanned. However not all of these have a scan convertor attached — which is the only easy way of feeding the image signal directly into the unconventional raster of the analyser avoiding the intermediate photographic processes. More importantly each different scanner would require a careful investigation of the effect of element shape and automatic scanning regime on the angular and spatial scatterer visualization.

The importance of the majority of the electronic system components is discussed in more detail elsewhere [23]. The vital feature of the display device, if photographic methods are used as the intermediary between the scanner display and the analyser, is linearity between the amplitude of the electrical signal input and the optical intensity displayed. This may, alternatively, be assessed as an overall linearity between the amplitude of the electrical signal and the intensity of the light fed to the image analyser, whether analogue or digital (see section 2). If the latter is used, as in this study, considerable care must be taken to ensure that each stage of the process — exposure, development, fixing — is controlled to make it as reproducible as possible; and the reproducibility should be continuously monitored.

In the present study, although no control was exercised in the initial photography of the display, all the subsequent processes were automatically controlled. Some evidence for the achievement of an adequate level of reproducibility may be elicited from the consistency of the "grey-levels" corresponding to total darkness and total brightness on the scans analysed (Fig. 4). Although the procedures may have been adequate for the particular analysis performed, which emphasises the shape of the curve, rather than its position on the axis, it would be necessary to demonstrate its adequacy if another type of analysis was performed.

5. The practical implementation and role of quantitative analysis

With the evidence for the regularity of scattering structure which is suggested by NICHOLAS and HILL [24], it would appear that twodimensional spatial Fourier transformation of the displayed image might yield interesting results. That this may be achieved by digital techniques is evident, if demanding in terms of computational resources. The main argument in favour of analogue (optical) methods, in spite of photometric problems, is the lack of a major sampling limitation in one direction (for television displays the limitation occurs perpendicular to the scan lines). This argument is reinforced by the immediate simultaneous display of spatial Fourier transforms in all directions. It is worth noting that if a small area is selected for Fourier analysis, the resolution of spatial frequencies will be limited by a relationship identical to that quoted for the equivalent time-domain problem [10].

For all other types of analysis, digital techniques are likely to prove most effective and rapid. For empirical tissue characterization (with all its limitations [11]) it is clear that the optimum approach would be to read from the scan convertor directly into the image analyser. Various types of analysis could be attempted on the material system under test, with a view to producing a purpose-built microprocessor based system for commercial implementation. The main disadvantages of this are, of course, the fundamental ones outlined in section 4, which may limit the successful extent of a particular (apparently appropriate) type of analysis to one diagnostician and his apparatus. Alternatively, individual A-scans may be digitized and analysed, but any processing at all (e.g. [25]) that is involved in reducing the amount of data to economic proportions, computationally, will need careful consideration in terms of its influence on the significance of the final image analysis that is performed.

With whatever system is chosen, empirical studies are possible and may lead to significant advances in selected areas. They will nevertheless be without the benefit of scientific understanding, and as RHYNE has pointed out for biological tissues, they are capable of an infinitude of variation. Instrumental development in these circumstances can only be guided by a popular (subjective) idea of a "better" picture which has no objective grounds or direction. It may be argued that the human eye — particularly that of a skilled practictioner — is more subtle and flexible in its analytical capability than any computational system. Whereas the present author would in no way dispute this, it does appear that it is important to direct investigations in such a way that ultrasonic scanners are optimized in terms of their imaging capability. Whereas scientific procedures for the investigation of inhomogeneous systems are of clear importance, they are also extremely difficult and complex [12], and it is proposed that the type of quantitative analysis described above may be a crucial element in both optimization of visual display, and in the development of our fundamental understanding.

It is generally agreed that the languages for the description of images, their structure and content are not well developed [26], and may need to be confined in their application to specialized fields or particular aspects of a problem. As yet no such specialized vocabulary exists for ultrasonic grey-scale images of inhomogeneous systems, and the development of such terminology is certain to be somewhat hampered by the differences that are produced of one object (or system) with different machine settings, and (more grossly) with different machines. Furthermore there is, at the present time [27], no clear consensus on calibration techniques or test objects or test images for ultrasonic pulse and continuous wave imaging systems. Some of the elements of these problems are discussed in reference [27], although the two papers concerned with ultrasonics avoid many of the crucial problems of detail discussed above.

The author suggests that the analyser discussed in the earlier part of the paper may be used as a bridge, or common point of reference. It may be used to provide a language basis or set of objective physical measures for the displays which on one hand are to be optimised for perceptual discrimination, and on the other hand are to be investigated with regard to the way in which they are affected by such factors as material composition and properties, transducer beam pattern, and signal processing.

A simple example may illustrate the practical importance of this approach. It is not intended to be specific to the analysis which has been employed: the methodology is the prime concern. Consider three typical curves from Fig. 4: *1A*, *3B* and *3C*. It may be possible by perceptual studies to determine a rank order for these (or any other shape of curve) in terms of the perceptual sensitivity to slight changes that they provide. A parallel investigation can be made, using this same arbitrary choice of numerical analysis and data display, of the way in which, with a particular type of material, the shape of the curve is affected by the transducer beam pattern and subsequent signal processing. Forging a compromise between these effects and the perceptual studies will permit the optimum visualization of that material to be performed. In other words it will permit that choice of the physical parameters of the instrumentation that can be varied which will present a display of the material in which changes in its scattering properties are most susceptible of perception.

The methodology outlined above is not in "closed form", since it depends upon a particular choice of numerical analysis and data display (Fig. 4) which is essentially arbitrary, and other displays (e.g. Figs. 5, 6) or analysis are numerous. Perceptual studies may permit a rank ordering of the benefits of the different analyses but limits to this will arise from the extent of the experiments performed and the conceptual frameworks within which they are conducted. Thus although optimization in an absolute sense may be impossible, in the shorter term the use of objective criteria as a pivot for development, however arbitrary, would appear to be only of benefit.

It has been suggested [12] that for human tissues, a direct link may be made between pathology and display. The extent of potential benefit can more clearly be seen in its application to model systems of known characteristics [27]. In this context it can provide extremely useful information on the extent of variations in acoustical parameters that can be detected, as well as the effect of their shape, spatial extent and distribution, on the image produced. In connection with parameter variation over a scale that is smaller than can be measured remotely by present techniques, the physical aspects of ultrasonic image formation in tissue and their relative importance may be assessed (in terms of arbitrary indices). The language of communication thus established can lead to comparison of results between laboratories and will inevitably lead to the demand for higher standards in the description of the ultrasonic systems used.

6. Conclusion

The pilot study presented, using an expensive commercial image analyser has shown the feasibility of deriving quantitative indices from ultrasonic grey-scale *B*-scans of inhomogeneous systems that reflect the textual discrimination that is visually achieved. The potential of this technique in empirical materials characterization for developing microprocessor-based equipment to give numerical indices of a specific diagnostic problem is clear. Such techniques will still be instrumentation dependent and the main value of the types of analysis presented is in using the indices to optimize the display for visual perception. Further extension to inhomogeneous systems whose microstructure is known will permit the optimization of ultrasonic visualization systems to an extent which is only limited by the arbitrary nature of the visual indices used. The cost of the analyser which has significant flexibility, prohibits the widespread development of these studies, and work is in progress to assess the feasibility of transferring data from different laboratories to one central analyser. The results of these studies will be reported in a future communication.

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References

[1] R. C. Chivers, H. J. W. Dudley, *The use of an image analyser for dimensional quantification in ultrasonic images,* Archives of Acoustics, **5**, 2, 169-180 (1980).

[2] A. Denier, *Essai de detection de masse tumorale du cerveau par ultrasonoscopie,* Comptes rend. soc. biol., **140**, 763 (1946).

[3] D. H. Howry, *A brief atlas of diagnostic ultrasonic radiologic results,* Rad. Clin. N. Am., **3**, 433-440 (1965).

[4] G. Kossoff, *Measurements using ultrasonic techniques,* Proc. Roy. Soc. Med., **67**, 135-140 (1974).

[5] R. C. Chivers, *B-scanning and holography in ophthalmology,* Ultrasonics, **12**, 209-213 (1974).

[6] J. M. Reid, R. A. Sigelmann, M. G. Nasser, D. W. Baker, *The scattering of ultrasound by human blood,* Proc. 8th Int. Conf. Med. Biol. Eng., Chicago, 10-7, 1969.

[7] C. R. Hill, R. C. Chivers, *Investigations of backscattering in relation to ultrasonic diagnosis,* Ultrasonics in Biology and Medicine (L. Filipczyński. ed.), 119-123, PWN, Warsaw 1972.

[8] R. C. Chivers, *The scattering of ultrasound by human tissue* (Ph. D. Thesis), University of London, 1973.

[9] R. C. Waag, R. M. Lerner, *Tissue macrostructure determination with swept frequency ultrasound,* Proc. 1973 Ultrasonics Symp., Monterey, California, IEEE **CHO 807-8SU**, 73 (1973).

[10] R. C. Chivers, C. R. Hill, *A spectral approach to ultrasonic scattering measurements,* Phys. Med. Biol., **20**, 799-815 (1975).

[11] R. C. Chivers, *Tissue characterization,* Ultrasound Med. Biol., **7**, 1-20 (1981).

[12] R. C. Chivers, *Some scientific and technical aspects of medical ultrasonics,* J. Med. Eng. Tech., **5**, 128-133 (1981).

[13] *Quantimet image analysers — a bibliography,* Cambridge Instruments Ltd., Royston, Herts, U.K.

[14] C. A. Taylor, H. Lipson, *Optical transforms,* G. Bell, London 1964.

[15] G. Harburn, C. A. Taylor, T. R. Welberry, *An atlas of optical transforms,* G. Bell, London 1975.

[16] C. P. Burckhardt, *Speckle in ultrasound B-mode scans,* IEEE Trans. Sonics and Ultrasonics, **SU-25**, 1-6, (1978).

[17] P. Atkinson, M. V. Berry, *Random noise in ultrasonic echoes diffracted by blood,* J. Phys. A., **7**, 1293-1302 (1974).

[18] R. C. Chivers, *Phase and amplitude fluctuations in the propagation of acoustic waves in inhomogeneous continua with velocity, density and bulk modulus variations,* Report No. 41/78 IPPT-PAN, Warszawa 1978.

[19] R. C. Chivers, *Phase and amplitude fluctuations in the propagation of acoustic waves in inhomogeneous continua with velocity, density and bulk modulus variations — results,* Ultrasound Med. Biol., **4**, 353-361 (1978).

[20] R. C. Chivers, P. A. Lewin, *A comparison of different designs of miniature hydrophone probes,* Proc. Ultrasonics International, Graz, 434-446, Iliffe Press, Guildford 1979.

[21] R. C. Chivers, *Some practical considerations in the measurement of the output of medical ultrasonic devices,* J. Med. Eng. Tech., (submitted for publication).

[22] R. C. Chivers, L. Bosselaar, P. R. Filmore, *On the effective area for diffraction correction,* JASA, **68**, 80-84 (1980).

[23] R. C. Chivers, *On the analysis of ultrasonic images of inhomogeneous materials including human tissue in vivo,* Ultrasonics Report 7902, University of Surrey Guildford U.K., 1979.

[24] D. Nicholas, C. R. Hill, *Acoustic Bragg diffraction from human tissue,* Nature, **257**, 305-6; **261**, 330 (1976).

[25] J. Milan, *An improved ultrasonic scanning system employing a small digital computer,* Brit. J. Radiol., **45**, 911-916 (1973).

[26] J. M. Evans, R. Kirsch, R. N. Nagel, eds., *Workshop on standards for image pattern recognition,* National Bureau of Standards, Special Publication, 500-508, 35-47, 51-81, Washington D.C., USA, 1977.

[27] R. C. Chivers, *On the purpose and practice of modelling in medical ultrasonics,* Proc. UBIOMED IV, (P. Greguss, ed.), 3-8, Visegrad, Hungary.

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