The application of real-time medical ultrasonic techniques to NDT

David I A Lines
Diagnostic Sonar Ltd.
Livingston, West Lothian, EH54 7BX, UK
Tel: +44 (0)1506 411877
Fax: +44 (0)1506 412410
E-mail: dave.lines@diagnosticsonar.com

Abstract

Medical ultrasonic imaging evolved as a spin-off from non-destructive testing (NDT) but the two techniques have since developed largely in isolation. In particular, nearly all medical equipment uses phased arrays for real-time imaging.

A paper was presented at NDT'83 [(1)] to review the state of the art of medical ultrasound and identify some of the techniques that could be transferred from medical imaging to NDT. The purpose of this new paper is to review the progress in both fields over the intervening 20 years and to outline what technologies could be transferred in the future.

1. Introduction

Medical ultrasound imaging evolved from NDT. Although there were some A-scan instruments, used for identifying the mid-line in the skull to assess if one side of the brain was swollen, it soon became clear that the preferred technique was the B-scan. Early systems used a gantry that constrained the probe within a plane and also measured its position so that the acoustic information could be drawn into the appropriate location on a storage tube display.

All of this changed with the advent of arrays for real-time imaging which allowed interactive scanning and the display of moving objects. The equipment then split into two categories:

- Small arrays that steer the beam to produce a high-refresh sector display suitable for cardiac imaging;
- Large arrays that step a large aperture across a linear or convex array head to produce a high-resolution image.

Dynamic focusing was introduced in the 1970s and this was followed by a steady series of improvements in functionality (e.g. Doppler spectral analysis, colour flow mapping, harmonic imaging and 3D reconstruction) and in performance (e.g. digital beam-forming, piezo-composites and 2D arrays).

The most recent developments include multi-beam processing, where more than one receive beam is produced from each transmission, and real-time 3D imaging (also known as 4D imaging).

2. Real-time medical imaging technologies

Medical ultrasonic imaging started as a spin-off from NDT - indeed every effort continues to be made to ensure that it remains non-destructive! However the relatively large size of the medical imaging market is just one of the factors that has driven the technology at a faster rate.

2.1 Comparison of requirements

It is appropriate to review the differences between the target materials (see Table 1) to be inspected.

Table 1. Comparison of target material properties.

Medical	Industrial
Usually similar properties	Many types and sizes
Velocity and impedance close to water	Wide range of velocities and impedance
Usually supports longitudinal waves only	Longitudinal, shear, surface & Lamb waves
Usually isotropic	Can be anisotropic
Usually attenuative	Wide range of attenuations
Deformable surface	Usually rigid surface
Often moving or deforming	Usually static
Safety constraints on power	No power level constraints
Mass market	Fragmented markets

2.2 The introduction of phased arrays

Phased arrays appeared in the early 1970s and they initially received a sceptical response as the image quality was poor and they were more expensive than the conventional gantry-based systems. However the market persevered because the real-time display offered the new capabilities of interactive imaging and the ability to view movement. The reason for the poor image quality – the small number of channels which produced severe grating lobes – was soon addressed and the quality exceeded the conventional capabilities when dynamic focusing appeared in the late 1970s.

The combination of dynamic focusing and interactive imaging was one of the main reasons that medical linear array systems were first tried in NDT for manual inspection of carbon fibre composite (CFC) aerospace structures (see Figure 1). The results were sufficiently encouraging that it has subsequently been followed by several generations of imagers.

Competition is a relentless technology driver and soon even the smallest portable scanner was using 64 channel digital beam-forming with continuous dynamic focus and frequency controls to drive 128 element piezo-composite arrays. Now the same portable package also includes Doppler colour-flow mapping and harmonic imaging.

Figure 1. Two generations of NDT array imagers for CFC. Diagnostic Sonar's System 185 (1978) and FlawImager (1988).

2.3 The next dimension

The image quality of the early real-time B-scanners was not as good as the existing units but the advantage of interactive imaging was sufficient compensation. The ability to show the image without apparent time lag as the operator rapidly changed the array's position and orientation allowed them to visualise the 3 dimensional structures beneath the array from this sequence of 2 dimensional images.

The obvious next goal was to reconstruct a 3 dimensional view from this sequence and eventually the computing power became available to achieve this. Some scanners acquired the 3 dimensional data set by monitoring the position and orientation of the array whilst others adopted the approach of mechanically scanning the array. The advantages of viewing the reconstructed image over a sequence of slices is easily appreciated by the viewing the 2D and 3D images in Figure 2.

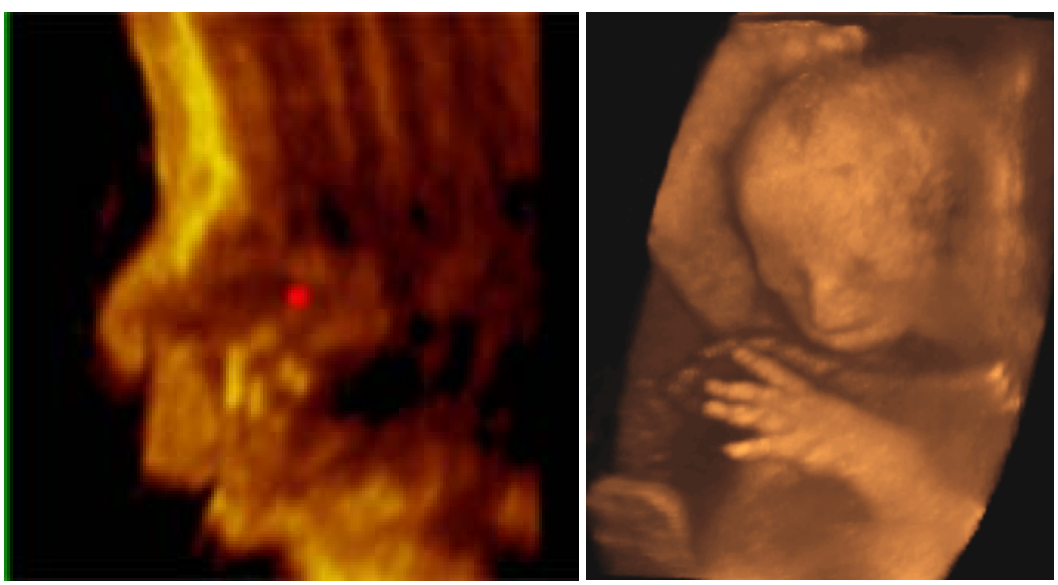

Figure 2. The advantages of viewing a 3D reconstruction (of a foetus) over a 2D cross section (of a foetal head).

The key problem in acquiring these 3D data sets is the time taken to acquire the large number of successive frames needed for a similarly high resolution in the 3rd dimension. Multiple-beam technology, where more than one receive beam is created from each transmit pulse, offers the possibility of increased frame rates, and this was introduced into DSL's scanners in 1985. However it was not until the market required these extreme frame rates so as to acquire and reconstruct 3D images in real-time (also termed 4D) has this approach become more widely available and systems with 4D frame rates of more than 15Hz are now available.

2.4 What can NDT learn from medical imaging?

NDT has already benefited from the developments in medical imaging. The gradual acceptance of phased arrays and the adoption of piezo-composite transducer arrays are examples where there has been a technology transfer – albeit somewhat later than envisaged in the review of 1983 (1).

The technology developed for very rapid B-scan imaging (2) has already been adapted to acquire 3 dimensional full waveform RF data sets on NDT specimens (3) and this is analogous to the 3D acquisition outlined above. It is possible in both cases to define the reconstruction operation as a post-processing operation. Although there is no NDT market demand for the real-time rendering performed for 4D medical imaging, it is likely that this will become available in the near future.

3. Conclusions

Although medical ultrasound imaging evolved from NDT, there has been relatively little technology transfer in the years since. The paper has outlined the latest developments in real-time medical ultrasound imaging and suggests the techniques that could be transferred to NDT.

References

1. D I A Lines 'The application of real-time medical ultrasonic techniques to NDT' NDT'98, Keele, September, 1983.
2. D I A Lines, K R Dickson, G Filippi and T Moir, 'A real-time image acquisition and processing system for ultrasonic arrays in NDT', Proceedings of NDT'99, The British Institute of NDT (ISBN 0 903132 27 3), pp.11-17, 1999.
3. D I A Lines, R A Smith, D Edgar, J M Bending and L D Jones, 'Rapid, low-cost full-waveform mapping and analysis using ultrasonic phased arrays', Proceedings of NDT 2003, Worcester, September, 2003.