A real-time image acquisition and processing system for ultrasonic arrays in NDT

David I A Lines and Kenneth R Dickson
Diagnostic Sonar Ltd.
Livingston, West Lothian, EH54 7BX, UK
Telephone: 01506 411877
Telefax: 01506 412410
E-mail: DiagnosticSonar@compuserve.com

Gianni Filippi and Tom J. Moir
Dept of Electronic Engineering and Physics, University of Paisley
Paisley, PA1 2BE, UK

Abstract

Ultrasonic arrays have not yet achieved any significant acceptance in NDT despite their almost universal use for medical applications. Diagnostic Sonar Ltd. (DSL) has expertise in both medical and industrial applications and this was exploited in a BRITE-EURAM project "RAPINSPECT" (1) to speed up the inspection of welds and so reduce costs. The design of the integrated ultrasonic array and how it can be used with existing equipment has already been described (2).

However, as is widely known from the medical imaging case, the best performance is achieved when the operator views, and interacts with, a real-time image. The data rates involved impose severe demands on equipment and this usually requires large, and costly, customised imaging systems. DSL has collaborated with the University of Paisley, under the UK's Teaching Company Scheme, to develop a PC-based reconfigurable computing system to perform the front end processing at the very high data rates needed for imaging. The architecture and capabilities of this system are discussed and some results are presented.

1. Introduction

Speeding up an ultrasonic inspection is highly desirable as the inspector's time represents a significant proportion of the cost and this becomes even more critical if equipment has to be shutdown or taken off-line during inspection. Manual inspection with single-element probes is widely used because it can adapt to the great range of materials and geometries encountered. The probes inspect at a point on the surface and so are not well-suited to area coverage, which is time-consuming and hence costly. The speed can be increased by automated mechanical scanning but this is complex, costly and inflexible.

Electronically-scanned arrays can achieve rapid area coverage without these constraints. They have been widely used in the medical field but have not yet made a successful transition into NDT because of the costs associated with customizing the array for the different target materials and surface geometries. Diagnostic Sonar Ltd. (DSL) has 25 years of experience with electronic arrays in medical and industrial real-time imaging systems and this was exploited, in a European-funded BRITE-EURAM project (RAPINSPECT) to reduce weld inspection time and hence cost (1, 2). This expertise has also been used to speed up the C-scan inspection of airframes (3 - 5).

Experience has shown that the array techniques would take a long time to achieve widespread acceptance unless they make extensive use of existing flaw detection equipment, techniques and operator skills. The modular family of arrays, developed for weld inspection (as shown in Figure 1a) and for other applications, can indeed be used with conventional equipment and skills, although the relationship between acquisition and display update on some digital flaw detectors may make them unsuitable for some applications (6). However, the best results are obtained when the array is operated with a data acquisition system which is capable of real-time imaging, as shown in Figure 1b.

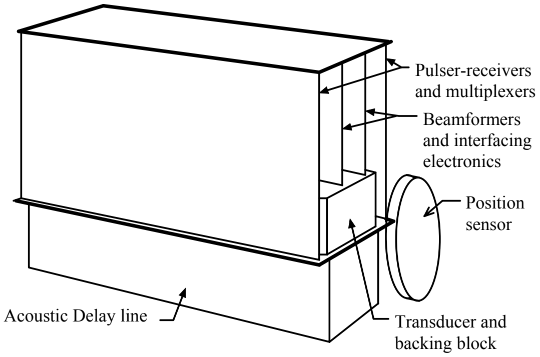


Figure 1a. Structure of array

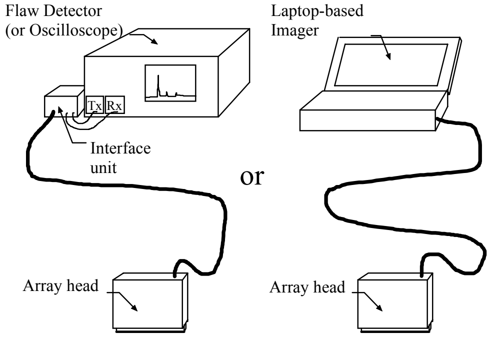


Figure 1b. Alternative modes of operation

This paper discusses the requirements of such a system and the architecture adopted to implement it. The paper outlines the way the modular arrays are operated and reviews the special requirements of the data acquisition and imaging system and the implementation is discussed with examples.

2. Imaging system

Although the array can be used with conventional flaw detectors, the best results are obtained when the full potential of the array (to acquire a set of A-scans with known positional relationship) is exploited. The operator can search interactively if the B-scan imaging is done in real-time. An interactive sequence of A-scans allows a flaw detector operator to build up a 2-D view in their mind and replacing A-scans with B-scans extends this perceived view to 3-D. Real-time B-scanning needs a customized data acquisition and display system but before discussing the requirements of such a system it is worth reviewing the limitations of the conventional flaw detector approach.

2.1 Limitations of conventional systems.

Interfacing with analogue flaw detectors is uncomplicated, since the A-scan display invariably shows each transmission. In RUN mode, the array beam position steps automatically at each transmission, so the A-scans from each part of the array are superimposed. Small sized flaws will only be displayed on a few lines out of the total in a sweep cycle and will therefore appear dim though visible. As long as the alarm is also updated on each line, then no flaws will be missed.

The operation with Digital flaw detectors is not so simple. The display is not updated on each transmission but usually at some significantly lower rate (typically 25-50Hz) and so will have a good chance of missing a small-sized flaw. Manufacturers rarely provide information on the display update in a way which allows operation with an array to be predicted - trying out is the only guaranteed approach. Experience so far shows a display with rapidly changing A-scan - this cycles round at the beat frequency between the array frame rate and the display update rate. One possible solution is to trigger the array's sequencing from the flaw detector's display update, though this is a signal which is unlikely to be available as an external connection. The alarms on digital flaw detectors are still usually monitored every line and therefore flaw detection is still possible with these instruments, though caution is appropriate.

Use with thickness gauges is even less well defined since the manufacturer will almost certainly regard the pulsing and measurement timing as proprietary information.

The imager must have a data acquisition sub-system which can handle the very rapid data rates associated with real-time B-scan images (typically 100x faster than needed for A-scans) but must also be able to avoid the frame rate beating problems above when displaying as A-scans.

2.2 Data acquisition and processing architecture.

The prime constraint on any data acquisition and processing system is that it had to be capable of handling the data transfer rates that are several orders of magnitude higher than for a conventional A-scan display system. The array design had been chosen for the ease of customization and the same argument was used to select between the hardware and software options available.

Designs for pulser-receivers with up to 20MHz capability are well understood. The aim was therefore to interface such a design to a digitizer and data processor that would be able to take data at the full sample rate and pulse repetition rates and derive the restricted data that was needed for the display. Even though a long display range might have been selected for a B-scan image, the rectified signals from a 5MHz transducer would still need to be sampled at around 50MHz to catch the shortest flaw echo. The job of the data processor is to derive the amplitude for each pixel in the final image, which might have come from over 100 samples for a long range, so that only this data has to be transferred to the display system.

The task to be performed can be broken down into large numbers of very simple processes but which have to be done at great speed. These can easily be handled by digital signal processors (DSP) but it would need several in parallel to achieve the desired speed. There was also a requirement for the generation of the timing signals for the pulser-receiver and DSPs are not well-suited to these tasks.

Application Specific Integrated Circuits (ASICs) could be used to achieve these tasks in parallel but they can be costly to develop and are not very flexible if the application requirements change.

An alternative, which retains the flexibility of a programmable system but can process fast enough by implementing many of these processes in parallel, is a Field-Programmable Gate Array (FPGA). This was available off-the-shelf as a re-configurable co-processor card with a PCI bus interface for rapid data transfer. It was fitted with a standard PCI Mezzanine interface which could be used to interface directly to the pulser-receiver card. It also contained dual banks of fast RAM with separate access from the FPGA and the PCI bus. It could therefore be configured to have the FPGA processing and storing a new image into one bank of RAM, whilst the previous processed image was read out of the other bank and onto the display. The block diagram of the data acquisition and processing system is shown in Figure 2.

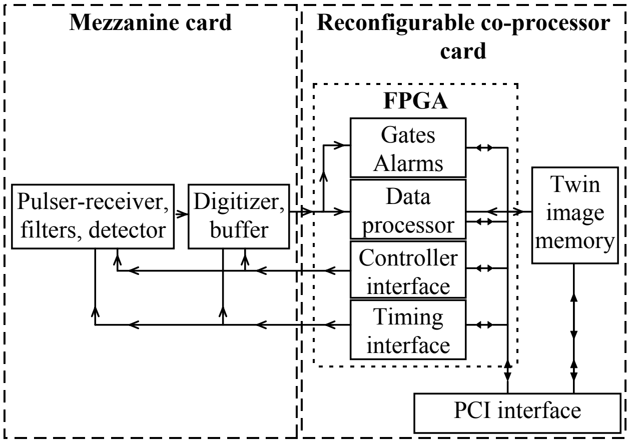


Figure 2. Data acquisition and processing architecture

2.3 Imaging software.

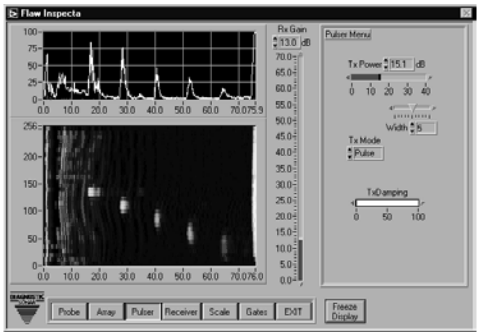
The co-processor card comes with a full set of C++ routines for loading hardware designs into the FPGA (in the same way that one would load a software routine to implement a particular function) and for transferring data to and from both the FPGA and the image RAM. LabView™ from National Instruments is a software package for developing virtual instruments within a Windows™ environment. It has a special set of routines for imaging applications and these were confirmed to be fast enough for the real-time B-scan data rates when used with the twin banks of RAM.

2.4 Processing capability and results

There are many advantages in using a 32 bit Windows™ environment, including: availability of low cost hardware and development software; built in storage and communications support allowing data and setups to be transferred between home base and the unit when in the field (even via the Internet); look-and-feel familiarity for rapid operator training. One disadvantage is that Windows™ is not a real-time operating system but this is resolved by the FPGA processor's ability to handle the real-time events, with data being transferred to the display when Windows™ is ready to process it. This can be done sufficiently fast that the whole system is effectively real-time.

When the array is in RUN mode (for automatic stepping of the beam position on each transmission) and the imager is set to mimic a conventional flaw detector, the processor calculates the maximum and minimum amplitude value at each range over all the A-scans since the last display update. This use of the maximum avoids missing any flaw and the minimum allows standard loss of coupling techniques to be used.

The imager starts a B-scan frame by sending the beam start, stop and pitch values to the array. The processor acquires the full frame into one bank of image RAM and then pauses. Whilst this was taking place, the previous image was read from the other bank of RAM onto the display. When complete, the banks are swapped and the process re-starts. The maximum and minimum A-scans are derived over this same frame period and are also displayed on the screen.


Rx Gain 13.0 dB

Tx Power 15.1 dB

Width 5

Tx Mode Pulse

Figure 3a. Project A-scan and B-scan from steel test block.

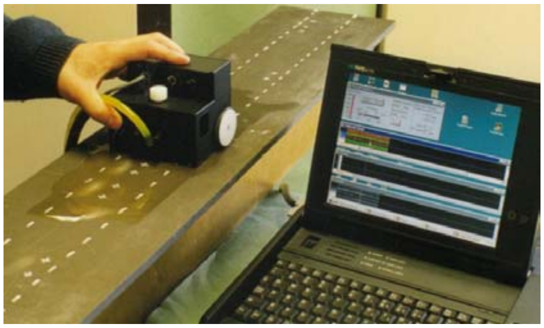


Figure 3b. C-scan imaging system on a Carbon Fibre Composite (CFC) spar.

Figure 3a is an example of the screen display for such a mode when an unfocused 3.5MHz array is used to scan a weld test block with an arrangement of 1.5mm side-drilled holes over a range of 76mm. The B-scan image shows the drop in amplitude and resolution of the target echoes with range (the array position corresponding to the left hand axis). The A-scan display is set to show the maximum amplitude at each range and hence all targets even though not aligned under the same beam. Alternatively the A-scan trace could be shown for any selected line of the B-scan image.

The other main imaging format is the C-scan. The A-scan display is used to setup the appropriate parameter for mapping (amplitude or thickness from up to 3 gates) and the image is then acquired - each line in the C-scan coming from a single sweep of the array. Figure 3b shows the system acquiring C-scans from a Carbon Fibre Composite Spar.

3. Conclusions

The limitations of single-element ultrasonic transducers for inspecting large areas have been discussed and the advantages offered by arrays introduced. Arrays are widely used in medicine but only in niche applications for NDT. DSL has tried to resolve this by developing a range of integrated arrays which have a common interface and allow operation with many conventional flaw detectors and with minimal operator training.

However, the best results are achieved with a real-time imaging system which is capable of A-, B- and C-scans. The requirements of such a system and how it can be implemented in practice has been presented along with examples.

The system is currently being evaluated for weld inspection, aerospace and corrosion applications. These are showing promise and further work will continue with the development of the arrays and the imager system on a range of other applications.

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References

1. BRITE-EURAM III project "RAPINSPECT" - Ref. BRPR950007.
2. D I A Lines, 'Rapid inspection using integrated ultrasonic arrays', INSIGHT, Vol 40, pp 573-577, 1998.
3. S J Willsher and R A Smith, 'Multi-element ultrasonic scanning of in-service airframes', INSIGHT, Vol 40, pp 154-159, 1998.
4. R A Smith and S J Willsher, 'Multi-element ultrasonic linear arrays for rapid lap-joint inspection', Proceedings of 2nd Joint NASA/DoD/FAA Conference on Aging Aircraft, Williamsburg, NASA/CP–1999–208982/Part 1, pp294-302, 1999.
5. R A Smith and S J Willsher, 'Multi-element ultrasonic transducers for rapid lap-joint inspection', Proceedings of NDT'98, The British Institute of NDT (isbn 0 903132 26 5), pp 87-90, 1998.
6. D I A Lines, K R Dickson and G Filippi, 'Rapid manual inspection and mapping using integrated ultrasonic arrays', Proceedings of 2nd International Conference on Emerging Technologies in NDT, Athens, 1999.