MODULAR, SCALABLE ULTRASOUND DATA PROCESSING ARCHITECTURE PROVIDES A FLEXIBLE, COST-EFFECTIVE SOLUTION FOR MEDIUM-HIGH COMPLEXITY SYSTEMS

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Abstract: In this work we present an scalable ultrasound data processing architecture, developed by INTERLAB Ingeniería Electrónica y de Control SA with the requirements of modern ultrasound inspection systems in mind.
The multi-channel processing architecture presented herein has been successfully applied to the development of a variety of industrial ultrasonic inspection systems, ranging from 5-channel stand-alone ones, to a massive 192-channel system controlling the quality of rolled steel plates.

Introduction: Current trends in NDT systems include demand for features such as: automatic or semiautomatic real-time operation, adaptability to inspect different parts produced within the same plant, capability to generate and manage reports on inspected parts, easy configuration to different quality standards and operation within the LAN or CAM in-plant facilities.
These demands are leading to an evolution from the classic single or dual channel hand operated systems towards complex automatic or semiautomatic systems that integrate multi-channel ultrasound data processing, databases for inspected parts and quality standards, interfaces to in-plant facilities and User Interface which allows easy and complete inspection system management.
Thus, modern, automatic inspection systems are made up by integration of three main components (see figure 1):

- Electronic hardware used to generate, capture and process the ultrasound signals.
- Software, from low-level algorithms, used to process the hardware-captured data to higher level MMIs used to present the results and handle parts and standard databases.
- Electromechanical subsystems used to scan the probes along the inspected part according to the planned inspection strategy.

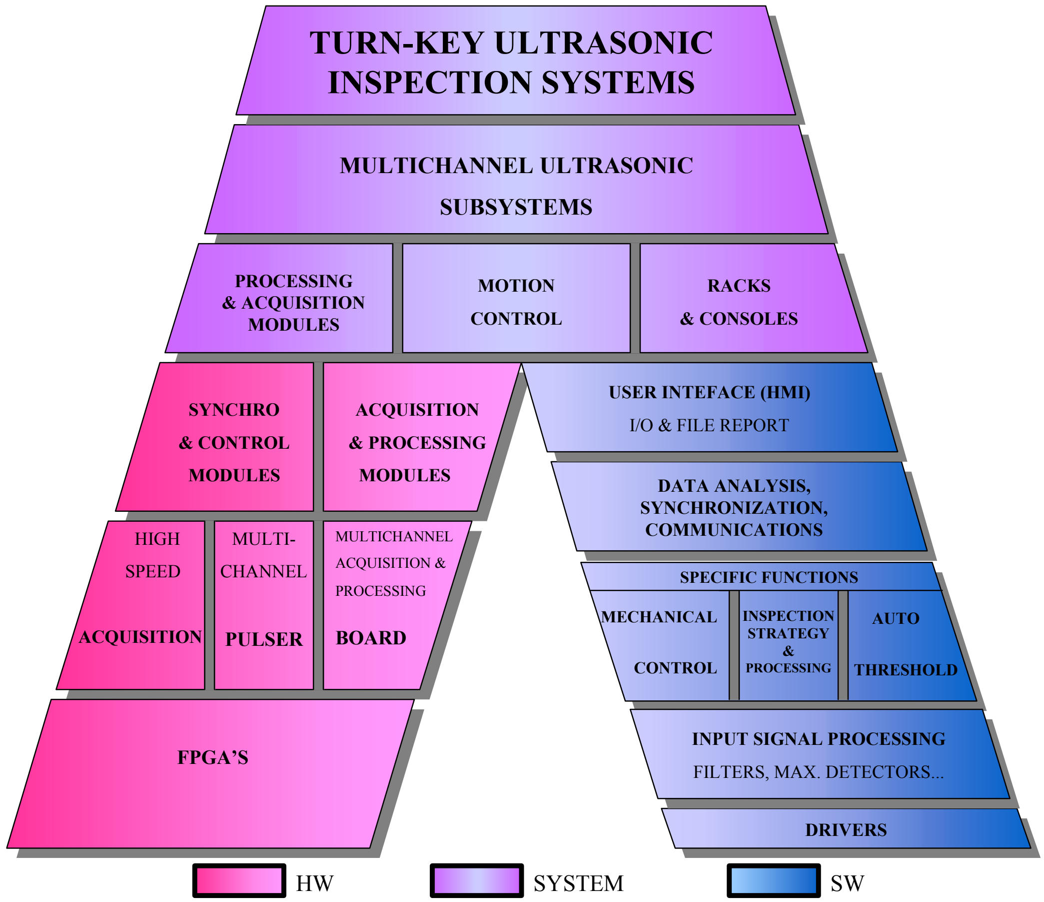

Figure 1. Main components of automatic inspection systems

Of course, the requirements for these three components can vary in a very wide range depending on the application where, for example, inspected part shape and size affect number and operating frequency of ultrasound probes (HW channels, sampling rate) but also the design of the electromechanical subsystem that scans the probes along the inspected part, and the quality standards applied have significant impact on processing software complexity, that can range from simple accept/reject criteria to a complex set of different quality levels according to distribution and size of defects.

But the requirements for similar applications may also widely vary depending on the end user. Thus user-oriented requirements range from complete turn-key systems to only the ultrasound processing hardware and the basic firmware drivers.

Throughout years of work in the field of ultrasonic NDT, both in quality control of manufactured parts and in preventive maintenance INTERLAB Ingeniería Electrónica y de Control SA has developed ULTRASEN®, a scalable ultrasound data processing architecture specifically designed to suit the wildly varying requirements of modern ultrasound systems. This architecture is based on the TU-200, an ultrasound data processor board, capable of managing up to 8+8 independent ultrasound channels. This board uses 64 bit DSP and FPGA devices to perform advanced data processing (which can be specifically programmed for each application) and transmit processed data. Where more than 16 channels are required, the necessary number of TU-200 boards can be stacked together and interconnected via the industry standard VME bus, with no added computational cost to the system, since data processing is performed locally on each board.

Processed data from TU-200 boards can be interfaced to a PC hosting the HMI software and the databases for inspected parts and applying quality standards. This PC can operate stand-alone or provide hardware and software interfaces to operate integrated within LAN or CAM in-plant facilities.

Hardware Architecture: A bottom-up diagram displaying how the modular, scalable ultrasound data processing architecture is built around the TU-200 processor board as shown in figure 2.

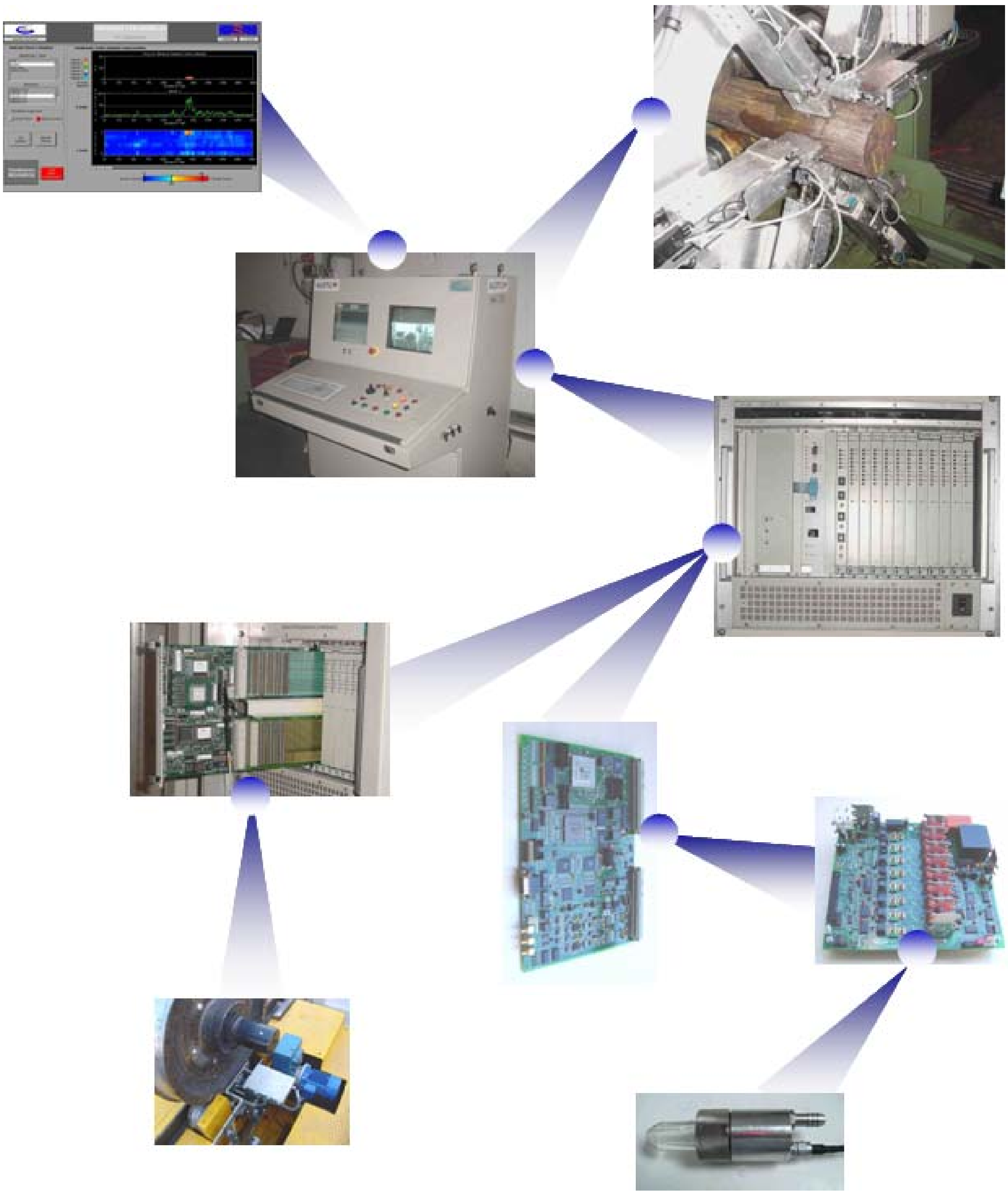

Figure 2. Complete ultrasound system built around TU-200 ultrasound processing board

Up to 16 ultrasound probes can be triggered by the Pulser module (see figure 2). The received signals coming from each of these probes are multiplexed and preamplified within the Pulser itself, an then transmitted through a high noise immunity differential line to the analog front-end of the TU-200.

For applications requiring more than 16 channels, more sets of Pulser and TU-200 processor boards can be added (one set for each additional 16 channels group). Since each TU-200 board performs local digital processing of its 16 channels, the system can be scaled to the necessary number of channels without increasing overall computing time.

The required number of TU-200 boards can be stacked in a rack along with the necessary power drives for the electromechanical subsystem that completes the ultrasonic inspection system.

Therefore, the ultrasound data processing architecture is based on the fully programmable ultrasound data processing board, the TU-200, with the internal architecture displayed in figure 3.

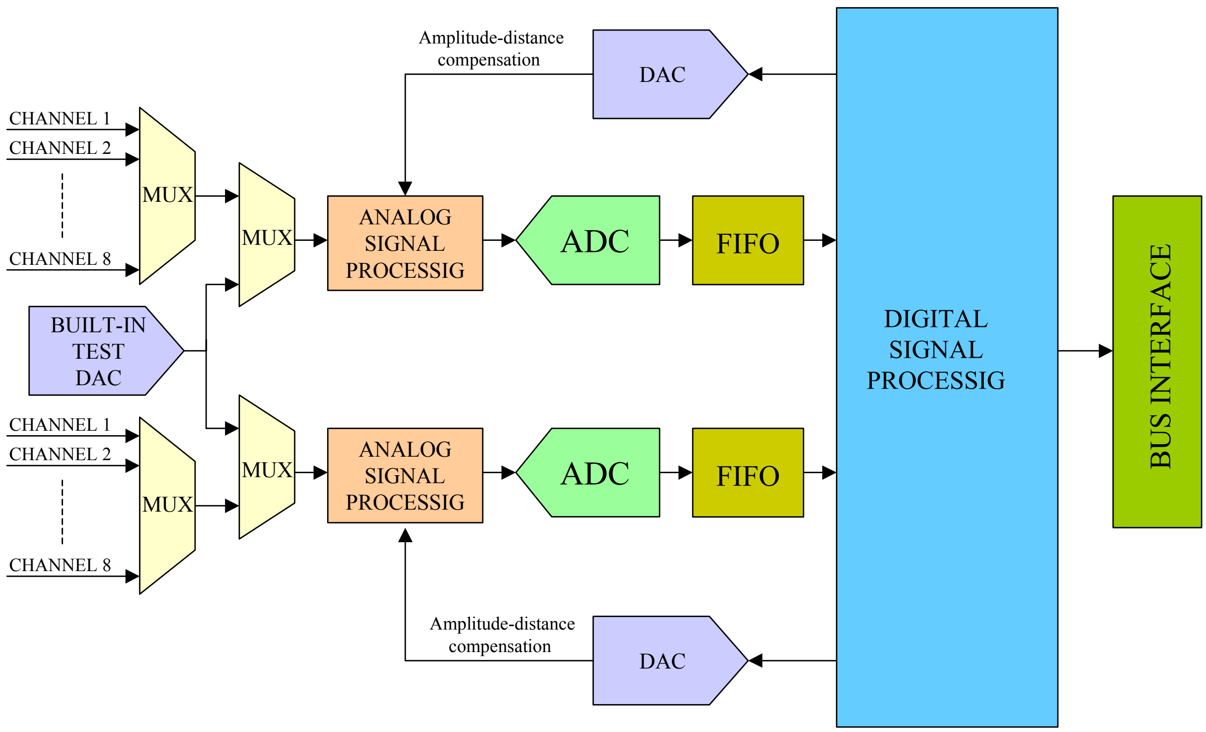

Figure 3. Internal architecture of TU-200 ultrasound processing board

First of all, the TU-200 generates the trigger pulses, which are used to trigger the ultrasound probes as required, via the external Pulser. Triggering is fully programmable, and can be synchronized to any of the following sources (or a combination of them):

- External trigger input.
- Encoder based trigger.
- Internal timer trigger.
- Software trigger.

Encoder based trigger is used to synchronize firing of the ultrasound probes with their position on the inspected piece, i.e., to synchronize the ultrasound processor with the electromechanical subsystem. For this purpose, each TU-200 board features eight encoder inputs.

The ultrasound echoes captured by the probes are multiplexed by the pulser and fed to the TU-200 via its analog front-end. This front-end amplifies the received signal as needed, using two different amplifiers:

- Fixed gain amplifier, with gain independently programmable for each probe of up to 50 dB, adjustable in 0.2 dB steps.

- Amplitude-distance compensation amplifier, with time dependent gain, of up to 50 dB , adjustable in 0.2 dB steps. Independent time-gain look up tables can be programmed for each probe.

The amplified ultrasound signal is digitized in the A/D converter (see figure 3), with a sample rate of 340 Msamples/s and resolution of 12 bits per sample (for special applications a high speed version featuring 600 Msamples/s and 8 bits per sample is available).

Once digitized, the ultrasound signals are processed in a 64 bits digital processor subsystem. Since the required digital signal processing is specific to each application, the digital processor subsystem is implemented using fully programmable DSP and FPGA devices. Some processing features common to a wide range of applications are:

- Digital echo-start.
- 2-D digital domain filtering.
- Four independent programmable amplitude-time gates, with maximum amplitude echo detection and simultaneous detection of up to 16 ultrasound echoes within each gate, defined by a set of programmable parameters (amplitude threshold, echo width, echo separation, etc.)

The processed ultrasound signals can be transferred to a PC hosting the HMI software via VME A24:D16 or PCI 32bit/66MHz buses, depending on board version.

Software Architecture: The software architecture is based on library modules, so that most of the low-level software modules are reusable and common to most applications, and only part of the HMI and database software tools need to be application-specific.

Following the same bottom-up approach of the preceding paragraphs, the software architecture can be described as follows:

Hardware Drivers: Each board includes specific drivers that allow full programmability of its features.

Basic Ultrasound Signal Processing: This includes all the basic processing algorithms performed within the digital processor of the TU-200 boards. While some applications require specific algorithms, there are a set of functions common to most applications, such as amplitude-time gates, maximum detection and echo-start.

Application Specific Processing: Once processed within the TU-200 boards, the ultrasound data are transferred to the PC hosting the HMI and high level software, where they are processed according to application-specific parameters such as part geometry, expected flaw location. Depending on the application, ultrasound data can be processed in the amplitude and/or time domains to identify potential flaws, which are then evaluated according to user-defined standards.

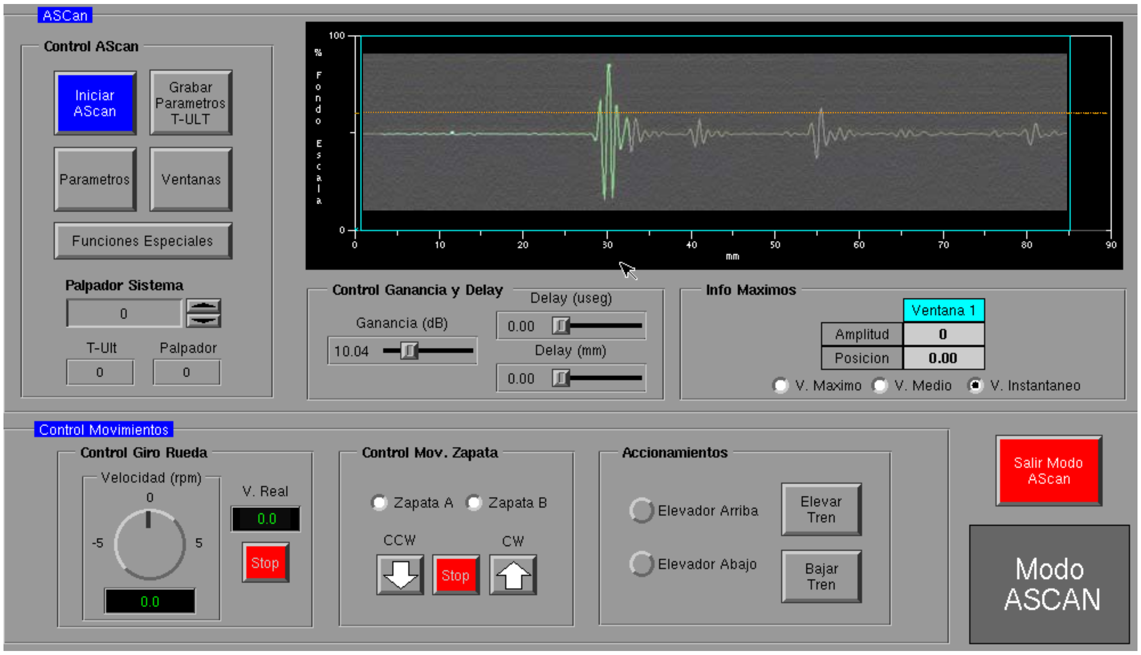

Figure 4. Sample of A-Scan visualization tool.

<u>Software Tools for Data Analysis:</u> The system includes a set of software utilities designed to help the end user make the most of it. Some of the common tools included in most systems are:

- A-Scan visualization tool(see figure 4): this presents the ultrasound echoes for each probe in the conventional amplitude versus time format. Basic TU-200 processing features, such as fixed and time-dependent gain, amplitude-time gates or activation of echo-start can be accessed to from this tool. The A-Scan tool also provides application-specific access to the electromechanical subsystem, so that the selected probe can be manually scanned along the inspected part.
- Database of Inspected Parts: The results for each inspected part are individually stored in a database, so that they can be recalled when needed.
- Inspection Result Visualization Tool: This tool is for the visualization of inspection results, and is tailored to the geometry of both the inspected part and the expected flaws. A sample is shown in figure 5, displaying D-Scan (B-Scan and C-Scan) inspection results for steel rods. Echo amplitude threshold can be adjusted on both the B-Scan and C-Scan displays to help discriminate flaws from noise.

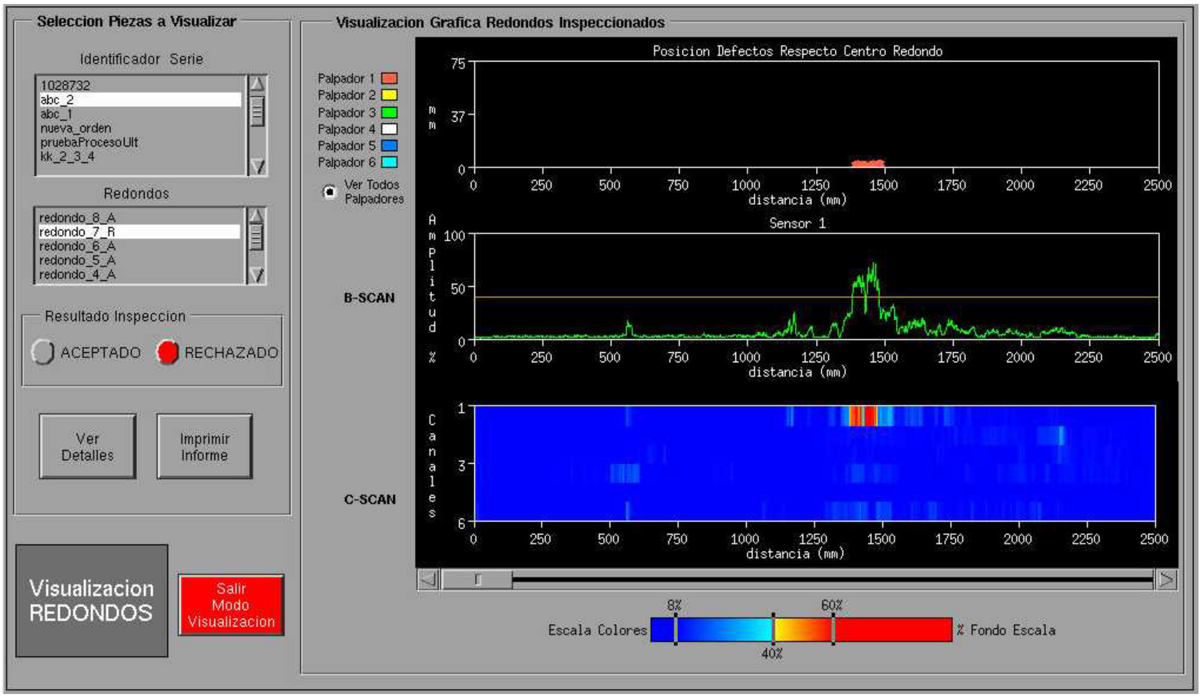

Figure 5. Sample of Inspection result visualization tool.

- Inspection Reports: Using this tool, a hardcopy report including inspection results and parameters as specified by end user is generated.
- System Maintenance: This tool is used to check the proper operation of different elements in the electromechanical subsystem, by providing access to each input/output signal.
- Configuration Tool: used to view or edit the operational system parameters.
- Alarm Tool: used to display and warn of anomalous or faulty system conditions.
- Backup Tool: used to create backup copies of the inspection result or standard databases, or system configuration files.

<u>Human-Machine Interface (HMI):</u> The HMI includes all the software functions used to control and operate the inspection system. It runs on a LINUX OS in a PC and uses the standard input/output console. It is developed with Xforms, a GUI toolkit based on Xlib for X Window Systems. Along with this software library, the HMI uses others developed by Interlab, such as the tools described above. Some common HMI functions are:

- Selection of operational mode.
- Visualization and management of inspection results.
- Generation of hardcopy reports.

Results: The ultrasound data processing architecture described in the present work has been successfully applied to a variety of ultrasound inspection problems with different types and degrees of complexity. Some examples of developed systems are:

- Inspection of rolled steel plates[1] of 6 to 60 mm thickness up to 3 m wide and up to 30 m long: In this case the scalability and massive parallel processing capabilities of the ultrasound processing architecture were the main issue, since the complete inspection system has to process the data from 192 channels in a maximum time of two minutes.

- Inspection of train wheels[2] for cracks around the brake mounting drills: This was a cooperation project between ALSTOM, who designed the electromechanical subsystem, and Interlab, that supplied the hardware and software for ultrasound data processing. This application required 6 ultrasound channels, and specific time-domain digital signal processing which was performed by the TU-200 processor. This system has been certified by RENFE, the Spanish railroad services operator, as the approved standard for train wheel inspection.
- Inspection of the solder plane in chain links[3]: In this application four 45º angle-beam probes are used to scan the weld area in studless chain links for off-shore applications, yielding enhanced flaw detection in the inner zone of the weld area as compared to single probe manual inspection.

References:

[1] J. A. Fernández, E. García, J. L. García, J.L. Rendueles, P. Rodríguez "192-Channel Automatic Ultrasonic Inspection System for Heavy Steel Plates" 8th ECNDT, june 2002.

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[3] R. Sevilla, E. García, C. Suárez, D. Blanco, N. Beltrán, J. Navas "Automated Studless Chain Inspection System" 8th ECNDT, june 2002.