ON A HIGH RESOLUTION ULTRASONIC INSPECTION SYSTEM

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INTRODUCTION

With increased demand for higher resolution ultrasonic evaluation, computer-based systems or workstations now become essential. In this paper a typical high resolution ultrasonic inspection system is presented. HIRUSIS, an mnemonic for HIgh Resolution UltraSonic Inspection System, is developed primarily for the purpose of high performance hidden flaw characterization and feature-based classification. The basic system comprises a PC (Personal Computer), a Pulser/Receiver and a Digital Oscilloscope as shown in Fig. 1. The system is further supported by several customized software packages for remote control of the devices, signal acquisition and presentation, one-dimensional and multi-dimensional signal processing, pattern recognition and B-scan image reconstruction. More image processing softwares will be added in the near future.

With HIRUSIS, we are now able to investigate the characteristics of hidden flaws in great detail by observing the interaction between the ultrasonic pulses and the hidden flaw in several domains. Signals may be processed on-line once acquired or stored in disk for later retrieval for off-line analyses. From these signals, we can build up a trained data-base (TDB) for automated classification of defect types. Emphasis will be placed in this paper on system design concepts and illustrative computer results with the use of the system.

PULSE GENERATION AND RECEPTION

The pulser/receiver we use is a model 5052UA Ultrasonic Analyzer from Panametrics. This device has a bandwidth of 35 MHz to which transducers of a broad range of frequencies can be connected. Basically, there are two modes of operation: the Pulse-Echo mode and the Through-Transmission mode. In the Pulse-Echo mode, a single transducer is used both as the ultrasonic transmitter and receiver. In the Through-Transmission mode of operation, separate transducers must be used as transmitter and receiver. Another advantage of the Pulse-Echo mode of operation is that access to only one side of the test block is required.

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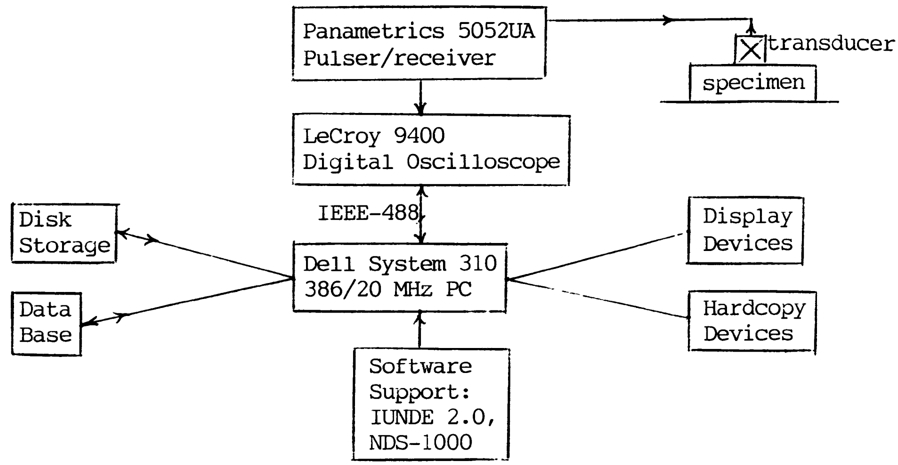

Figure 1. A block diagram representation of HIRUSIS, the HIgh Resolution UltraSonic Inspection System.

Also the transducer can be connected to the test specimen by contact mode (as shown) or water-immersion mode. The pulser/receiver should be selected according to specific inspection needs.

DIGITIZING THE ULTRASONIC SIGNALS

There are two possible ways to digitize ultrasonic returns in HIRUSIS. The first one is by using a LeCroy 9400 digital oscilloscope, which has a bandwidth of 125 MHz. Similar scopes are available from Tektronix, Data Precision, etc. This device is capable of one-shot sampling at rates up to 100 megasamples/sec and interleaved sampling (or repetitive sampling) at rates up to 5 gigasamples/sec. Two input channels are available, each with 32000 words of memory buffers. Inputs may be pre-filtered to avoid aliasing.

This scope is also equipped with some arithmetic (such as differentiation and integration) and spectral analysis software in association with a high resolution display. However most of the signal processing capabilities of HIRUSIS are performed on the PC. There are two options available for transferring data between the PC and the digital scope: (a) via an RS232C port or (b) via a GPIB port. Asynchronous serial communication using RS232C, though easier to program, is not as flexible as using GPIB. Only one device can be linked through one serial port, say COM1 from the rear panel of the PC. Also data have to be transferred in ASCII format which brings the performance further down. A maximum data transfer rate of 19200 baud is possible with RS232C Communication. On the other hand, parallel communication using GPIB and IEEE-488 bus is more flexible and efficient. Multiple devices may be linked together and data can be transferred in either binary or ASCII format. A maximum rate of 400 Kbytes/sec is achievable using GPIB communication. Although a program written for GPIB communication may be a bit lengthier and look more complicated, it simply works better once you get it working.

The second way to digitize an ultrasonic signal in HIRUSIS is by using a STR *825 board (from Sonetek) which fits into a full size 8-bit or

16-bit expansion slot in the PC. This board has a single input channel and contains 16 Kbytes of on-board RAM that are used as memory buffers as the analog signal is being digitized. Analog signals can be digitized at rates up to 200 MHz using interleaved sampling technique. Any 4K of the 16K memory buffers can be memory-mapped to within the PC's 1 Megabyte addressable space. Therefore, the digitized data are easily accessible by addressing these memories. This method completely eliminates the need for communications between the PC and peripheral devices. Furthermore, this kind of digitizing board is much cheaper than a conventional digital oscilloscope. The price of such a board varies from $1500 to $2500 while the price of a digital scope varies from $15000 to $20000. However. the STR *825 board has several drawbacks. First of all, it does not have front panel keys or knobs to let users change certain parameters such as sampling rate and delay. Secondly, the board does not have its own display unit and has to rely on the PC's monitor to show the signal that is currently stored in the buffer memories. These facts imply that extra programming is necessary to simulate the capability of a scope on the PC. To program a board like this requires the use of low-level programming language (80x86 assembly language). Anyway, though with a slight loss in performance, C can be used instead of, or in combination with, assembly language, which greatly relieves our programming loads. As a matter of fact, the costs of these software developments easily exceed the cost of the board itself.

ABOUT THE PC

A PC forms the main processing, control and storage unit of our system. The signal processing, pattern recognition and device control functions are carried out by softwares developed by ourselves as well as by other vendors. The PC we use is a Dell System 310 with 1 Megabyte (expandable to 16 Megabyte) memory. It has a 20 MHz 80386 CPU, a 80387 math co-processor, a 40 Megabyte hard disk plus a 1.2 Megabyte floppy drive. We also use a VGA (IBM standard) monitor which is capable of displaying 256 colors or 64 intensity levels simultaneously in 320x320 resolution or 16 colors in 640x480 resolution. Fig. 2 shows a typical plot of long window data after digitization by LeCroy digital oscilloscope and a short segment of the long window data. The sampling rate is 100 MHz. To plot the long window data, the computer takes one out of every ten samples. The experiment uses a plastic ball of diameter 8/32 inch in water-immersion mode with transducer frequency of 10 MHz.

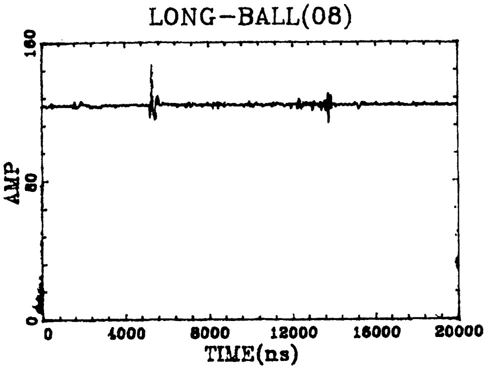

Figure 2a A long window data of 20000 ns duration.

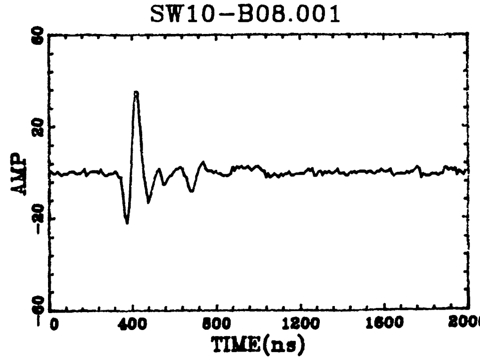

Figure 2b A short segment of data of 2000 ns duration.

SIGNAL PROCESSING SOFTWARES

Processing of the signals can be done on-line or off-line using the software package IUNDE version 2.0 (see [1] for more details), which contains options to remote control the actions of the digital scope via an IEEE-488 bus. An earlier version of this package was reported in [2]. Digitized signals can be transferred from the digital scope to the PC via the same bus for other domain analyses.

Each transformation of the original signal can be regarded as a domain; e.g., spectral analysis can be regarded as the spectral or frequency domain, the original signal as the time-domain, etc. Domain analysis can be 1-dimensional such as the spectral domain, or 2-dimensional such as the bi-spectral domain, or multi-dimensional in general. Domains can be combined such as the Wigner-Ville distribution domain which is a combination of time and frequency domains.

The following is a brief description of the functions provided by this package. Basically, these functions are divided into 4 groups:

(a) Signal Acquisition

1. Acquire signal from a disk file (in ASCII format)
2. Acquire signal from STR *825 board
3. Acquire signal from LcCroy 9400 digital scope via GPIB

(b) Signal Processing

1. Power/Magnitude Spectrum by FFT
2. Power/Magnitude Spectrum by Burg's Technique
3. Power/Magnitude Spectrum by Chirp-Z Transform
4. Correlation and Correlation Spectrum
5. Bi-correlation and Bi-spectrum
6. Deconvolution by Wiener Filtering
7. Deconvolution by Spectral Extrapolation
8. Deconvolution by Least Mean Square Error (LMSE) Estimation.
9. Hilbert Transformation
10. Analytic Signal
11. Wavelet Transformation
12. Power Cepstrum
13. Miscellaneous - Mean Removal, Moving Average, Circular Shift, Zero-Padding, Amplitude Normalization

(c) Graphic Display

1. Display 1-D signals
2. Display 2-D signals in 3-D surface plots
3. Display 2-D signals in 2-D contour plots
4. Display multiple signals on one screen

(d) Feature Extraction and Automated Defect Classification

Options are provided to extract certain features from the time and frequency domains. Automated defect classification is done by using the Nestor Development System (see next section) based on these features. With the data provided by the Army's Materials Technology Laboratory, we have trained a "neural memory" to recognize defects of different geometries.

PATTERN ANALYSIS

Time domain representation of the original signal theoretically contains all the information about the signal. However, in many cases, it is difficult, if not impossible, to tell certain characteristics of the signal observed in the time domain. Signals, therefore, should be transformed to other domains such as frequency analyses which may amplify certain hidden features of the time domain signal.

The data available in each domain is usually quite immense which causes certain problems such as large disk space for mass-storage of data and expensive computations and memories required for pattern recognition. Therefore, a higher level of abstraction in the signal representation is in order. Instead of using the entire data set, several features are extracted from each domain for pattern recognition. Using this approach, features from different domains can be easily combined to form a compound vector which is better known as a "pattern".

In HIRUSIS, two different approaches to pattern recognition are available. The first approach is by using classical techniques such as Nearest-Neighbor (a non-parametric method) and Bayesian (a parametric method) classifications. These functions are collected in the software package PARECO 1.0 (see [1] for more details). In addition, several optimal feature reduction functions such as Foley-Sammon transformation and Multiple Fisher's Discriminant are also available in PARECO. The following is a brief description of the functions provided by PARECO:

1. K-mean Clustering
2. Nearest-Neighbor Classification
3. Bayesian Classification
4. Foley-Sammon Transformation
5. Multiple Fisher's Discriminant
6. Nonlinear-Mapping
7. 2-D Scatter Plots

The second approach applies modern neural network technologies. Pattern recognition is based on the Nestor Development Systems (NDS 1000) purchased from Nestor Inc. The actions taken by this software system depends on a user-defined system architecture and several parameters. The system architecture is made of 1 to 6 levels and each level is made up of 1 to 6 units. Hence, there can be a maximum of 36 units in a system architecture. The core of each unit is a 3-layered neural network which is called the RCE or Reduced Columb Energy network by its inventors [3]. Each unit, based on its associated network, admits patterns via the input layer and performs its own training without interfering with or being interferred by other units. In other words, the actions of these units are completely independent of each other. Therefore, we may use different features and/or patterns of different dimensions in each of these units.

When a pattern is presented into a unit, three types of responses are possible. These are the "Identified", the "Uncertain" and the "Unidentified" responses. Each level in the system architecture is associated with a Unit Agreement Number which should be between 1 and the maximum number of units in that level. The functions of this number is to determine the system's response to an input pattern based on the responses from all units. For example, suppose there are 5 units defined in level 1 and the unit agreement number is set to 4, then the system's response at this level will be "Identified" if and only if 4 out of the 5 units respond with "Identified". If this criterion is not matched, the system will defer its response to the next level, if any, or give other responses depending on the system parameters and the status of the units. In the normal case of network training/testing, there should be no or very few "Unidentified" responses, while all patterns with "Identified" system responses are correctly identified and the percentage of "Uncertain" responses kept to a minimal. Fig. 3 shows a flow-chart for a typical development cycle using NDS. A trained data-base or "memory" can eventually be built up for efficient automated classification. This

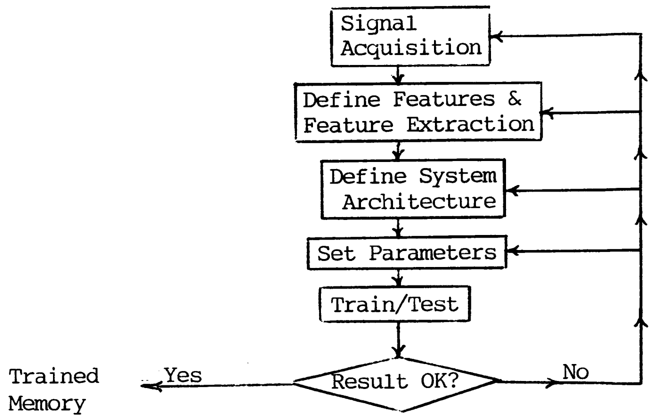

Figure 3. A typical development cycle using NDS for classification.

memory can be updated or improved at any time by further training, provided more specimens are available. Detail descriptions about NDS, the action of an RCE network and the tactics for defining the system architecture and choosing the system parameters can be found in [3].

The reliability of these pattern recognition approaches, however, depends on many factors; e.g., the size of the training set, the fitness of the features extracted from different domains and the precision of the acquired signals.

IMPULSE RESPONSES

As illustrative computer results, Fig. 4 shows impulse responses for a typical ultrasonic pulse echo of a hidden geometrical defect [4] as obtained by deconvolution using (a) Wiener filtering, (b) spectral extrapolation, and (c) L2 or LMSE estimation. The software package IUNDE Version 2.0 provides a convenient tool to plot the impulse responses. Details of the deconvolution techniques are described in [5].

OTHER UTILITIES

These utilities include a program for B-scan image reconstruction, a program for 2-D Wiener-Filtering of a B-scan image and feature extraction and graphics routines. In the near future, other image processing softwares will be developed and customized for HIRUSIS.

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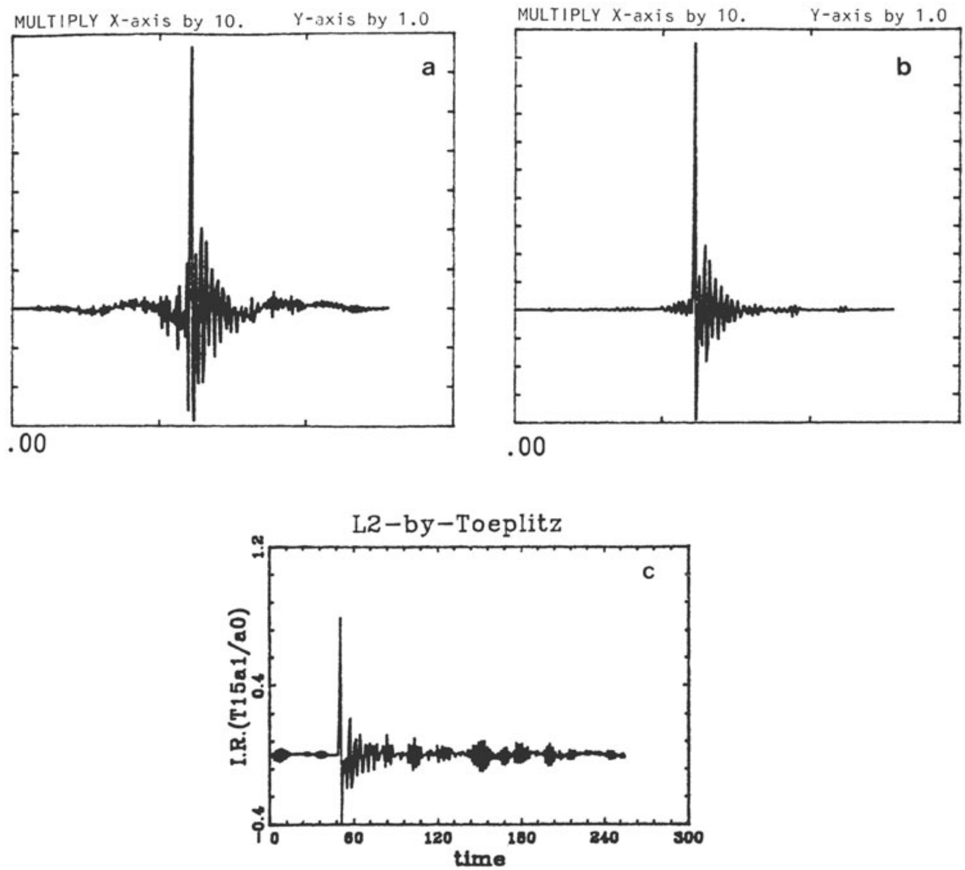

Figure 4. Impulse responses obtained by deconvolution using (a) Wiener filtering, (b) spectral extrapolation, and (c) LMSE estimation.

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