AN ADVANCED APPROACH FOR POINTWISE NDE IMAGING

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INTRODUCTION

Nondestructive evaluation (NDE) techniques are widely used in manufacturing and service industries for quality assurance and related applications [1]. Depending on the sophistication of a given NDE procedure, the inspection result can be in a form of a simple go/no-go indication, an amplitude readout, a list or a table of measurements, a two-dimensional figure, or an image which correlates test results with material and defect parameters. An image presentation which directly correlates measured NDE parameters with component coordinates is generally the preferred way of displaying results. Recent advances in computer and electronic technology have also facilitated the development and operation of image acquisition, processing, and presentation for many NDE techniques.

Based on the underlying physical principles of NDE imaging methods, images can be acquired in two forms depending on whether or not the sensor or specimen is manipulated with respect to the other. Many imaging systems such as thermal imaging, laser imaging, and X-ray, hold the source and sample stationary while using an electronic scan, mechanically controlled scanning mirrors or video frame capture to acquire images. Other systems such as ultrasonic C-scan and eddy current imaging, have to rely on a mechanical scanner to physically maneuver the probe relative to the specimen point by point over the area of interest to acquire images.

Due to hardware and software constraints, it is difficult to devise a position-driven closed-loop pointwise measuring system. Data acquisition is commonly accomplished by either stop-and-go or fixed rate sampling. The first approach achieves positional accuracy but prolongs scan time and increases the wear of mechanical components. The second approach sustains the throughput but compromises positional accuracy. In this paper, we present an approach to rectify these deficiencies by utilizing interrupt-based communications between microprocessors to synchronize NDE measurements with mechanical positions on the fly. The advantages are: (1) optimization of scan parameters, (2) improved positional accuracy, (3) reduced wear and tear on the mechanical components, and (3) increased throughput.

BACKGROUND AND APPROACH

The hardware of a typical pointwise NDE imaging system consists of three major components: a system controller, instrumentation, and a mechanical scanner. An embedded microprocessor or a dedicated personal computer is normally used as the system controller to control instruments, command movements, and acquire data. Dedicated instruments and electronic devices are used to excite the sensor and measure desired signal...
parameters. A mechanical scanner and associated hardware fixtures such as probe and specimen holders are used to relatively scan the sensor over the area of interest on the specimen.

There are two fundamental types of image acquisitions: analog and digital. In analog systems, a pen plotter is mechanically or electrically linked to a mechanical x-y scanner. One approach is to use a voltage/current converter to energize the plotting electrode with a proportional signal amplitude. A gray scale image is created in real time with varying intensity gray dots as the scanner traverses over a sheet of electrostatic discharge paper. Another approach is to use a voltage amplifier/mixer to combine the signal voltage with x-y positional voltages for the generation of a pseudo 3-D line-plot image on a x-y plotter. Although NDE images are normally produced in real time, analog imaging systems have no data storage/retrieve capabilities. Redundant scans have to be made to optimize the image and produce duplicates.

In most digital systems, a resident analog to digital (A/D) converter in the computer is used to digitize the proportional voltage signal at a fixed sampling rate. As long as the A/D conversion rate is much faster than the mechanical scan rate, an NDE image can be generated with a good degree of accuracy. Advances in digital electronic and microprocessor technology have enabled digital instruments tremendous pre-processing and real-time processing capabilities. A stop-and-go (point-to-point) approach often has to be used to synchronize the mechanical movements with data measurements to achieve positional accuracy. This approach prolongs scan time and increases the wear and tear on the mechanical system.

The ideal digital pointwise imaging system is to command the scanner to scan at a desired speed and fetch measurements at the designed positions on the fly. We have developed a prototype ultrasonic imaging system, which uses interrupts generated by the mechanical system at the designed positions, to trigger and initiate the data acquisition routine for the measurements. The only constraint is that besides the A/D conversion rate of the digital instruments, the speed of the system is also limited by the data transfer rate of the interface buses.

SYSTEM CONFIGURATION

Ultrasonic C-scan imaging is a well established method for NDE applications[2-6] and thus is used to demonstrate the interrupt control mechanism. The improved system consists of a CompuAdd 325 PC (IBM-386 Compatible) as the system controller, a Panametrics 5052UA pulser/receiver with a gated peak detector and a Keithley 196 System DMM as the drive and measuring instruments, a Delta Tau Data Systems PMAC motion controller card, Compumotor Plus drivers/motors, and a Daedal X-Y table with linear encoders as the mechanical scanner. The block diagram of the prototype ultrasonic C-scan imaging system is illustrated in Figure 1. The system controller interfaces with the scanner using the PMAC mechanical controller card through the industry standard architecture (ISA) PC-bus and acquires gated amplitude data from the Keithley DMM through an IEEE-488 interface bus.

Firmware was developed to enable the PMAC to generate interrupts in the system controller as trigger signals to initiate data reads. Interrupt routines were developed using Borland C++ 3.1 programming package. The scan routine programs the PMAC with the scan parameters and pre-determined positions where measurements are to be performed. The PMAC microprocessor constantly compares the real-time probe position from the encoder feedback with the preset acquisition coordinates. An interrupt is generated by the PMAC Programmable Interrupt Controller (PIC) and received by the PC PIC when the positional conditions are met. The PC PIC subsequently generates an interrupt to PC CPU. This interrupt is used by the CPU as the trigger signal to initiate the data acquisition routine and synchronize other events. The PMAC PIC continually generates interrupts until the scan routine is completed. The interrupt structure between host controller and peripheral PIC is shown in Figure 2.
Since the encoders are independent of the mechanical drives, the interrupts are generated precisely at the desired coordinates. The only constraint is that the speed of the scanner is limited by the time needed to complete the data acquisition routine through the interface buses. Although the current application is for ultrasonic NDE data acquisition and image generation, the approach can be easily applied to eddy current NDE and other engineering systems.

LABORATORY EXPERIMENTS AND RESULTS

The most tangible benefit of the interrupt-based scan is the improvement in scan time as compared to a point-to-point scan. The data acquisition software has been modified to
enable the recording and comparison of the scan times for both interrupt and point-to-point approaches with exactly the same scan parameters such as scan speeds and index sizes. The ratio of the two scan times is calculated and used as the factor of the measurement of improvements. Identical scans are performed at least two times to ensure a proper estimate of scan times. The average scan time variation is approximately ten seconds or less.

The test specimen used for the benchmark tests is a 3 inch (76.2 mm) by 4 inch (101.6 mm) simulated aluminum block with six 0.375 inch (9.525 mm) diameter flat defects at various depths. The scanning velocity for x-axis and y-axis is set to be 0.5 inch (12.7 mm) per second. Three scan configurations are used for the experiments: (1) x-step size of 0.025 inch (0.635 mm) and y-step size of 0.025 inch (0.635 mm); (2) x-step size of 0.025 inch (0.635 mm) and y-step size of 0.050 inch (1.27 mm); and (3) x-step size of 0.050 inch (1.27 mm) and y-step size of 0.050 inch (1.27 mm).

One-transducer pulse echo configuration is used for the laboratory experiments. Ultrasonic pulses are transmitted to and received from the same transducer by the pulser/receiver. The timing gate of the gated peak detector is set to be between the front and back surface echoes for all scans. The analog signal amplitude is digitized with the digital voltage meter and sent to the host computer through an IEEE 488 interface. A digital C-scan image is subsequently generated with the acquired amplitude data and mechanical position information.

The C-scan images obtained are essentially identical for both the point-to-point and interrupt approaches. An example of the obtained ultrasonic C-scan images from the tests is shown in Figure 3. Ultrasonic amplitude variations are represented with 256 gray scale levels. Scan parameters and test results for the experiments are tabulated in Table 1. The main effect is that the interrupt scan maintains a constant speed along the scanning axis, during data acquisition, while the point-to-point scan must stop at designated intervals. As shown in Table 1 there is approximately a factor of two improvement in scan time for the interrupt scan as compared to the point-to-point scan. This factor of improvement is a function of the scan configuration such as scanning speed, data acquisition interval, and specimen size etc.

Figure 3. An example of the ultrasonic C-scan images (4"x3") obtained from the experiments.
Table 1. Comparison of the experimental results from point-to-point and interrupt scans

<table>
<thead>
<tr>
<th>Test Configuration</th>
<th>Point-to-Point</th>
<th>Interrupt</th>
<th>Factor of Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scan Area = 4&quot; x 3&quot;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>X velocity = 0.5&quot;/sec</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Y velocity = 0.5&quot;/sec</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>x-step size = 0.025&quot;</td>
<td>2375.49 sec</td>
<td>1013.52 sec</td>
<td>2.34</td>
</tr>
<tr>
<td>y-step size = 0.025&quot;</td>
<td>(160 pts x 120 pts)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>x-step size = 0.025&quot;</td>
<td>1192.42 sec</td>
<td>514.01 sec</td>
<td>2.32</td>
</tr>
<tr>
<td>y-step size = 0.050&quot;</td>
<td>(160 pts x 60 pts)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>x-step size = 0.050&quot;</td>
<td>1015.27 sec</td>
<td>526.10 sec</td>
<td>1.93</td>
</tr>
<tr>
<td>y-step size = 0.050&quot;</td>
<td>(80 pts x 60 pts)</td>
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CONCLUSION

In summary, we have (1) proposed a new approach by using an interrupt control mechanism to improve pointwise NDE imaging systems; and (2) performed experiments to verify the concept with an ultrasonic C-scan imaging system. Technical improvements include (1) optimized operating parameters; (2) reduced wear and tear on the mechanical system; (3) increased throughput; and (4) improved accuracy for data acquisition and image processing. These improvements translate to increased productivity and reduced cost in quality operations.

IBM-PCs and their compatibles are gaining in popularity as system controllers and host computers for many mechanical control, instrument control, and signal processing boards. IBM-PC based manufacturing, test and measuring systems thus are routinely being developed, introduced and implemented in various industries. This new approach of using interrupts to initiate and synchronize engineering events has immense commercial potentials; it can be applied to engineering systems in manufacturing, testing, evaluation, and monitoring such as material dispensing, packaging, sorting, and many other industrial applications. Further detailed information regarding these systems, including programs, can be obtained from the author.

REFERENCES