

## A NOVEL HIGH SPEED, HIGH RESOLUTION, ULTRASOUND IMAGING SYSTEM

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### OVERVIEW

We are reporting on the capability of our novel ultrasonic imaging camera system to rapidly characterize various materials. The ultrasound system is capable of imaging entire areas of internal targets at TV frame rates. This contrasts to conventional C-scan type systems which generate images only by moving a point by point sensor. The result is a tool which can provide real-time, large area imagery of subsurface faults.

It is important to perform characterizations of materials rapidly. More specifically, it would be highly desirable to:

1. Evaluate large areas of metals and composite materials quickly
2. Give immediate, user friendly imagery to an operator

The insertion of NDE technologies into material development with the ability to provide immediate production control feedback, and in-field structural health monitoring becomes more readily achievable. The basis for the technology is a patented ultrasound sensitive integrated circuit which reads out two-dimensional ultrasound data into a standard TV output, enabling ultrasound C-scanning in real time.

Although ultrasonic C-scanning was originally developed for inspection of homogeneous materials, the method has been now been applied to inspection for detection of corrosion, delaminations, porosity and inclusions, and to monitor the initiation and progression of damage resulting from applied mechanical loads and other environmental factors. The ultrasound imager builds on that capability by allowing these inspections to be made much more rapidly. The sort of problems encountered that we intend to monitor include real time imaging of:

1. Corrosion
2. Orientation of fibers
3. Fiber matrix/interface conditions
4. State of cure
5. Interlaminar cracks

## 6. Volume fraction

### NEED FOR IMPROVED C-SCANNING TECHNOLOGY

For the assessment of small imperfections, high resolution systems are required. Furthermore, measurements need to be made over large areas such as of an aircraft body. This requires considerable time to conduct these measurements and also places a severe burden on human inspectors to evaluate what they observe without being overcome by boredom and a lack of concentration. Automated systems are needed to assist the inspectors in the performance of their tasks. In order to establish improved screening and detection, a system which provides detailed visualization of a 3-D volume of materials is needed. This technology bridges the large gap between taking point by point scans of the materials of interest and evaluations that can be done quickly during the manufacturing process or after field use.

### APPLICATIONS

The installation of a real time C-scanning tool can be for any usage of C-scanning technology today, only thousands of times faster, and more easily implemented. Overall application benefits of such a tool include:

1. Better determination of economic impacts of aging systems
2. Easier implementation through low weight, portable probe
3. Better process control
4. Quicker in-situ inspection
5. Less defective products produced
6. Less operator intervention

Specific applications that we have addressed are as follows:

1. Real time corrosion imaging of pipes, aircraft, ships, storage tanks
2. On-line, large area aerospace composite production process control
3. Real-time, in-service composite aircraft inspection
4. Real-time automotive composite manufacturing inspection
5. Real-Time semiconductor package inspection

The implementation of the system for corrosion detection on aircraft is shown in Figure 1.

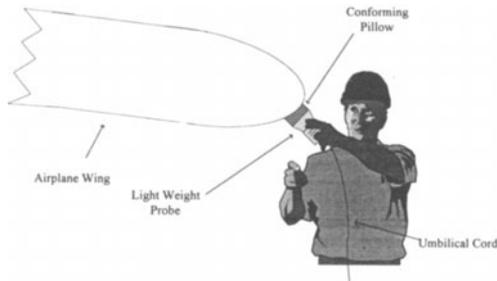


Figure 1. Real-time Ultrasound Imaging Implementation.

As the operator moves along the target under study, he or she would get immediate subsurface imagery as well as quantitative data. One user interface is shown in Figure 2, where the signal processed RS170 image of corrosion is shown on the right hand side (colorized, edge enhanced, etc.), and the left display shows the quantitative A-scan at the intersection of the crosshairs on the image (e.g. for detailed depth information). As the probe is moved, both the image and the A-scan would reflect the current position. Alternatively, the probe could be mounted on a track which scans along the surface of the aircraft skin and cover an entire area, with high resolution, in minimal time (10 to 15 minutes) and stored on video for later evaluation of areas of interest.

#### SYSTEM DESCRIPTION

The system is best described as a 'camcorder for sound'. Similar to a conventional camcorder which is based on CCD technology sensitive to light, Imperium has developed a novel 2D read out IC sensitive to ultrasound, not light. The technique can be used in either reflection (pulse-echo) or transmission. The transmitter is separate from the novel IC receiver. The system is broadband, working over a wide range of frequencies.

A large area, uniform ultrasound beam insonifies the desired target. In the reflection mode, the beam strikes the target and returns back towards the sensor. An acoustic lens is used to collect the resulting beam and focus the information onto the IC array.

The pattern formed strikes the ultrasound sensitive pixel elements (128 x 128) of the array. The voltage generated at each pixel is transferred to a silicon CMOS multiplexer which is designed to read out the individual voltages sequentially, producing a TV like image.

Signal processing provides 'range gating' by controlling the acquisition time of the array to occur when the ultrasound pulse generated by the source transducer returns from a predetermined depth within the target (e.g. 5 mm in depth). Each of the thirty frames per second can be

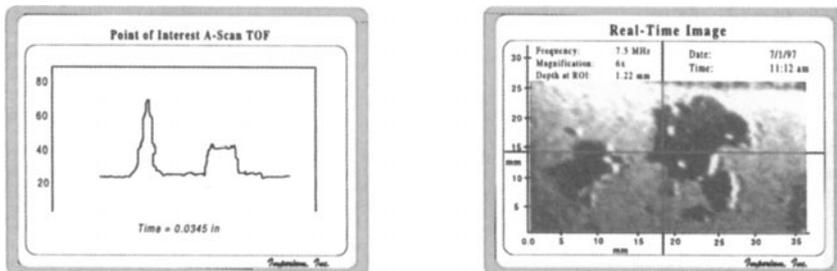


Figure 2. User Interface Screen.

programmed to return from a different depth, providing 3D information (e.g. 3 mm to 8 mm, with 1 mm increments). Alternatively, at a single depth, the frames could be integrated to provide enhanced signal to noise. The RS170 TV signal is then frame grabbed and coupled to a standard machine vision system which performs acceptance/rejection criteria, image enhancement, false color, image annotation, etc.

The separation of the receive and transmission functions is not intended to imply that they are to be physically separated from each other. However, the separation into the receive and transmission modes does point out the flexibility inherent in the design of the imager.

Our transducer array was made by bonding a piezoelectric array to a focal plane array multiplexer. An array we are evaluating is approximately 1 cm on a side (128 elements with 85 micron center to center spacing). If 85 micron resolution is desired, it could be achieved but with 1 cm area coverage. In this case, the target area covered is equal to the area of the array. However, if the required resolution is 1 mm, then by setting the lens position, an area coverage of 128 mm of the target will be achieved. Since the camera operates at 30 frames a second or higher, reasonably large areas would be covered in times much less than required by a point by point scan. Similarly, if higher resolution is required, magnification of the image will result in better resolution, but sacrifice area coverage. The objective is a 'zoom in' or 'zoom out' as the operator desires as shown in Figure 3. The ultimate resolution will be limited by the wavelength of the ultrasound employed.

All other approaches to ultrasonic imaging have used focused pulses, whereas our preferred approach requires spatially uniform insonation of the plane of interest. Uniform insonation is a research specialty of Dr. George Harrison and of the University of Maryland who have been teamed with Imperium Inc. in some of the efforts. He has the only published calculations and experimental realizations of such insonation fields. One highly uniform field is shown in Figure 4. For the improved spatial resolution, special transducers operating at center frequencies of 375 KHz, 1 MHz, 2.5 MHz, 5 MHz and 15 MHz were used for imaging. The size and shape of the source transducer was determined

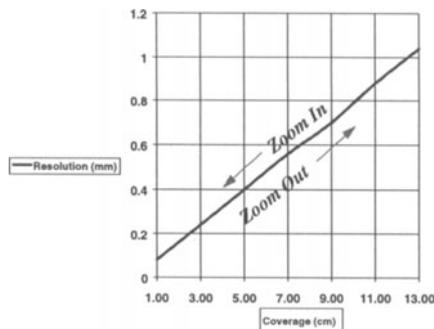


Figure 3. Adjustable 'Zoom' Selection.

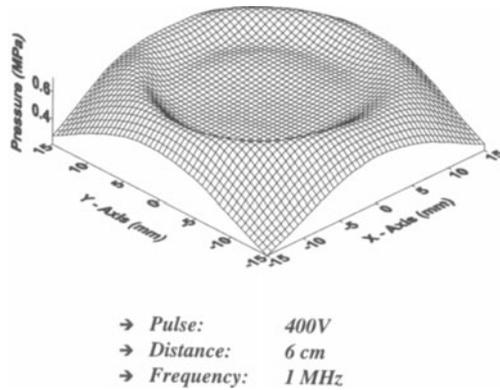


Figure 4. A Highly Uniform Pulse Used For Real-Time Imaging.

from field propagation simulations.

The influence of advanced signal processing and pattern recognition algorithms, and an enhanced hardware for ultrasonic non-destructive testing capabilities has been phenomenal. The recent systems store more data and analyze and image with good efficiency and hence make the whole system automatic and more reliable. Our TV formatted image is immediately adaptable to well developed commercial machine vision systems which perform immediate:

1. Frame grabbing of frames with particular features of interest
2. Conversion of shades of gray to color to bring out features not otherwise detectable, especially at higher frame rates
3. Intensity plots of image features rather than relying on image intensity to detect features
4. Dynamic range modification over different regions to enhance contrast beyond what is observed with uniform gain conditions
5. Edge enhancement
6. Image subtraction to not only look for changes, but also to remove fixed pattern noise
7. Image addition for improvement of signal to noise

#### REAL TIME IMAGES

Once real time images were obtained, a number of features of these images could be investigated.

A relatively small target, a 7 mm diameter metal washer was imaged. The width of the metal ring is approximately 2 mm. In order to obtain images for inclusion in this report, single frames of the video images were frame grabbed and then stored to disk. Figure 5 shows a framed grabbed image of the washer held by a clamp. By moving the washer to a position closer to the focal plane of the lens and refocusing the image plane at the plane of the array, the image size

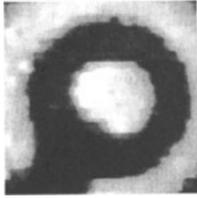


Figure 5. Without Zoom.



Figure 6. With Zoom.

increased. The enlarged image is shown in Figure 6. This is of course standard practice when operating in the visible and infrared regions of the spectrum. Mechanical C-scanning can provide the same information but at a much slower rate. It is the speed at which the images can be generated that makes this system unique. The Images in Figure 5 and Figure 6 below were taken at both 30 frames /second and at 50 frames/second. The real time feature greatly simplifies the focusing adjustment, allowing the operator to adjust the focus and then to readjust the focus if a different magnification is chosen.

Close examination of Figures 5 and 6 shows that the images are made up of a set of small squares or pixels. The smallest squares are generated by the actual pixel separation in the focal plane array. In this array the pixels are 85 microns apart. Knowing the pixel size one can determine the image size by counting the number of pixels across the image.

As a first approximation it is typical to invoke the Rayleigh criterion:

$$\theta_{\min} = 1.22\lambda / D$$

where  $\theta_{\min}$  is minimum angular separation of two points in the target,  $\lambda$  is the wavelength of the ultrasound signal, and D is the diameter of the lens. In fact, the resolution of a scanning system with high enough sensitivity and dynamic range can resolve the depth of the saddle point between the two point images and thereby improve on the achievable resolution.

Figure 7 is an image of an airplane rivet where a crack can clearly be seen emanating straight up. Figure 8 is an aluminum plate with a substantial amount of corrosion. The darker areas represent the more heavily corroded areas.



Figure 7. Aircraft Rivet with Crack Pointing Up.



Figure 8. Corroded Aluminum Plate.

It is important to point out that images of targets moving across the field of view, either by panning the camera or by moving the target, appear more detectable. The motion of details within the image catch the observer's eye and are readily tracked across the image plane.

#### CONCLUSIONS

A new generation of ultrasound NDT imaging equipment based on microelectronic techniques has been demonstrated. This system substitutes microelectronic processing for mechanical scanning and is therefore not only much faster than existing equipment, but inherently a lower cost system. Imperium is actively looking for technologically advancing organizations currently involved in nondestructive testing to determine the application specific product specifications that will meet the needs of the NDT industry.

#### REFERENCES

1. X. Zhang, G.H. Harrison, and E.K. Balcer-Kubiczek, Exosimetry of unfocused pulsed ultrasound. IEEE Trans. UFFC 41:80-83, 1994.
2. G.H. Harrison and E.K. Balcer-Kubiczek, Uniform Pulsed Fields for Ultrasonic Bioeffect Experimentation. Ultrasonics, 29:264-267, 1991.