REAL TIME RADIOGRAPHY

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GOODSON ENGINEERING, DENTON, TEXAS—For many years, the presence of radiography (x-ray) facilities in an engineering lab was the exception, rather than the rule. In a recently published article, one of the authors [MEG] lamented on the poor state of capabilities in many forensic engineering labs across the United States. More specifically, engineers are attempting to do work for which their labs are not properly equipped.

In prior years, the use of radiography in NDT (Non Destructive Test) meant that images were captured on film. In use, a source, either stand-alone or in a sealed cabinet, was used to expose film. The film was typically industrial grade x-ray film, with AGFA Structurix NDT film being a common staple. Unlike medical facilities, which need film developed in STAT (Short Turn-Around Time) fashion, industrial radiography film took between 10 ten and 12 twelve minutes to develop. Once developed, the radiographer would often re-shoot the image while adjusting exposure parameters (time, distance, voltage, current) so as to achieve acceptable or optimum results. It was not uncommon for an engineer to spend thirty 30 to 45 minutes in an attempt to get a good image of fire debris.

In the last year, the authors have installed two Real-Time Radiography (RTR) x-ray units in their lab. RTR differs greatly from the traditional film systems, in that the images are acquired and displayed in real time. This improvement alone cuts out the development time, as well as the cost of consumables (chemicals and film). Moreover, we have found that RTR imaging has brought about improvements in ways that were not expected, as follows:

- Manipulation of the artifact
- True microfocus capabilities
- Magnification
- Signal processing
- Video recording

Each feature is further described later.

BASIC CABINET UNIT

(Photo 1)
Nicolet x-ray cabinet

The unit consists of a source, a stage, a receiver (scintillation device), camera, signal processing circuitry, and display. For archival purposes, images can be stored on a hard drive in one of the usual formats — BMP, JPEG, TIFF.

(Photo 2)
Larger cabinet with Hamamatsu x-ray source

The writers heavily recommend that an engineering firm pursuing RTR make use of a sealed cabinet system. The cabinets are required to have a dual interlock, and are lined with lead to prevent leakage. The glass window to view the internal movement / manipulation of the part is lead filled to prevent leakage. The cabinet is normally inspected once a year for interlock function and leakage. The true appeal of the cabinet system (as opposed to carrying out work in a lead lined room) is that there is no requirement for exposure monitoring of personnel or the wearing of pocket dosimeters. From a regulatory standpoint, the licensing and documentation issues are much less burdensome when a sealed cabinet is used.

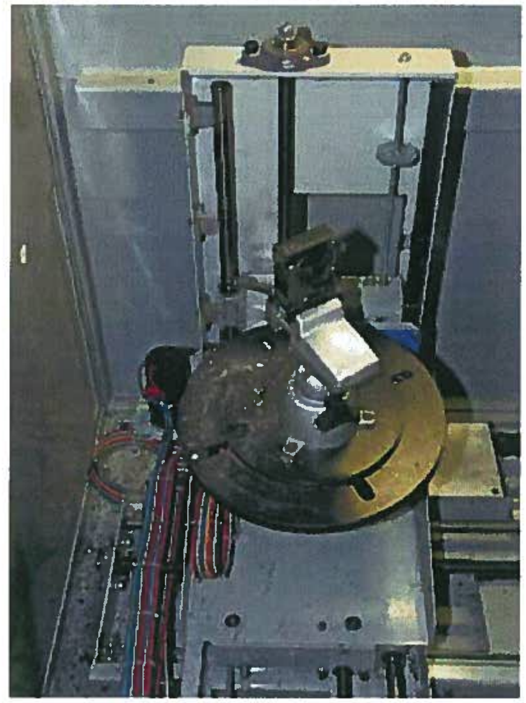
Photos 1 and 2 show two different sealed cabinet RTR systems.

MECHANICAL MANIPULATION OF THE ARTIFACT

The inclusion of a mechanical manipulator offers significant advantages to the user. A manipulator simply means that the x-ray system has several motors and stages present, allowing the user to position the object in regards to the x-ray beam. On a typical system, 5 axes of movement are ideal. These axes include 3 axes of translation (x, y, z) and two axes of rotation (tilt and yaw).

In real life, it is seldom that the object of interest will lie 'flat' in a field of resolidified fire debris. The ability manipulate the object so that the area(s) of interest is parallel to the source is one advantage of manipulating the object in real time.

The second advantage lies with the area of masking. We have examined numerous objects where the region of interest was hidden by other nearby metallic parts. When the part is rotated in real time, it is often possible for the interfering object to be taken out of the path between the source, imaging device (receiver), and the part of interest. This can also be done with film, but only with numerous and lengthy iterations.



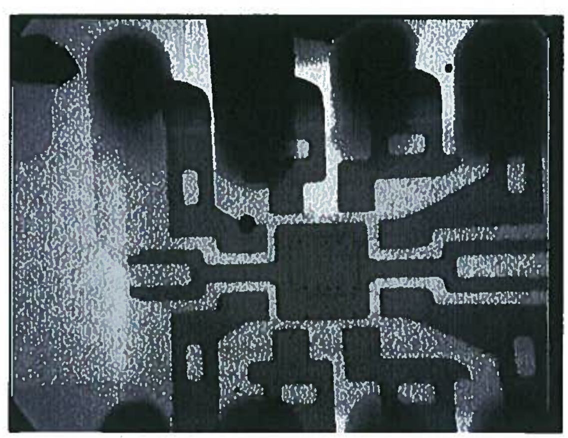
(Photo 3)
Five-Axis manipulator

TRUE MICROFOCUS CAPABILITIES

Microfocus refers to the small spot size used in some RTR cabinets. The spot size is related to how small in detail the system can image.

Photo 4 shows the outside of a typical DIP (Dual Inline Plastic) IC (Integrated Circuit). The metallic pins are visible from outside the package, while the internal wires are shown on Photo 5. These are 1 mil wires made of gold; it is not uncommon for an electronic failure to cause one of these fine wires to open up, just as how a fuse does. The microfocus capabilities allow this aspect of an electronic circuit to be examined and analyzed.

(Photo 4)
Dual inline plastic integrated circuit



(Photo 5)
RTR image of DIP IC showing 1 mil Au wires; this is the internal view of the same IC shown in Photo 4

MAGNIFICATION

When using both microfocus and manipulation (translation), it is possible to magnify small details so they are more obvious. The z-axis can be broken into two segments, with the first segment lying between the x-ray source and the object being examined. The second segment of this z-axis lies between the object and the scintillating device. As the object is moved closer to the x-ray source, the distance to the scintillation device will increase, causing the image to be optically magnified.

DIGITAL SIGNAL PROCESSING

Signal processing, or DSP (Digital Signal Processing), refers to an entire array of features that modern electronics brings to the RTR arena.

These features include:

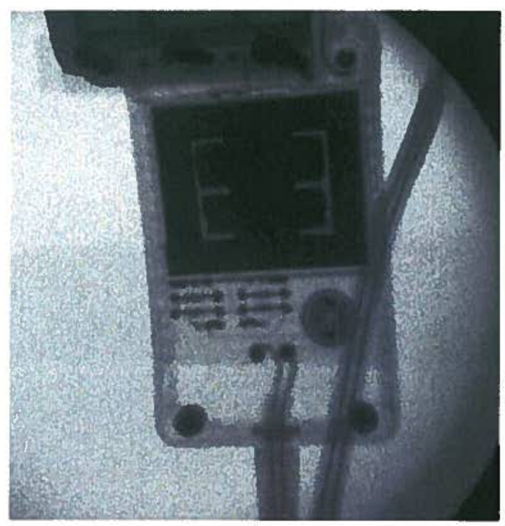
- Noise Reduction
- Variable integration times
- Image Enhancement

The camera acquires the light energy and digitizes into a pixel format, with 8, 10, and 12 bits of quantization being common. The output can be via USB-2 or Firewire. The camera signal is fed to a PC, which then uses software to display the image, as well as to provide a myriad of signal processing functions. The use of digital formats allows the images to be stored and accessed easily. Moreover, x-rays, being monochromic or grey scale, do not require the massive file sizes of standard SLR photography. This makes images very easy to e mail to clients. In addition, it avoids one huge disadvantage of films, that being the problem of duplication for multiple parties in litigation.

NOISE REDUCTION

The scintillation device, which concerts x-ray energy to light energy, will have some Noise Figure (NF.) The noise will manifest itself by pixels randomly appearing white on the display screen. If the image were thought of as a TV picture, the picture is one that has 'snow.' DSP techniques can be used to average the signal over time. As an example, the Nicolet NXR cabinet allows the user to select from 2 to 128 signals to be averaged over time. Photo 6 shows a portion of an AC to DC power supply (wall wart), while the same image in Photo 7 shows the effects of 16 frame averaging.

(Photo 6)
Internal view of AC to DC adapter, no signal averaging



(Photo 7)
Same AC to DC adapter averaged over 16 frames

VARIABLE INTEGRATION TIMES

The use of variable integration times is one of the most advanced features available with DSP and radiography. The value of DSP is seen when one has x-rayed a large mass that contains objects with many thicknesses and densities. If the x-ray energy is too strong, the thinner or less radio-opaque objects will not show up at all. If the energy is too weak, the obtained image will be substantially white, and this will have the effect of masking items of interest.

Using the DSP technique of variable integration times, an initial scan is done in real time. Those objects that are very dense will have collected signal levels that are extremely low. After this first scan, a bitmap is created, and each pixel is assigned a numeric value or weight, say ranging from 0 to 255, depending upon collected signal strength. Those pixels with numeric values of say less than 32 are considered to be very opaque. On the second scan, the scan is conducted with normal integration (signal gathering) times for every pixel with a value greater than 32. For those pixels with a value of less than 32, the integration time can be increased by a factor of 4 or 8, effectively increasing the gathered energy. The result is that a single x-ray can simultaneously show objects with vastly different transmissive characteristics with much greater detail on the same image.

VIDEO RECORDING

At first, there does not seem to be much of a need for video recording of RTR images. However, the presence of the manipulation stage can be combined with true video recording, such that as a part is rotated by way of tilt and yaw, data can be gathered. The user in essence creates a video recording of the part or object as it is rotated through its various positions. This is a much easier 'task' than causing 180 or 360 individual rotations (each 1 to 2 degrees apart) with the requisite separate exposures.

ARE WE ALTERING IMAGES?

About 8 years ago, one of the common concerns about the use of digital photography was that of unscrupulous investigators using software to manipulate photos, and thus evidence. The writers have been adamant in stating that this is not a software problem, but rather an ethics problem. Any investigator who would manipulate a photo in an unscrupulous fashion could just as easily taint a fire scene by spiking ignitable liquid samples. *(Note: For clarification, the authors are now referring to the changing of an image as a form of image manipulation; earlier in the article, we were referring to mechanical manipulation, which is simply a series of stages and motors that move the part inside the RTR cabinet)*

But to answer the question regarding image manipulation, the answer is in the affirmative; these DSP techniques are forms of image manipulation. However, the manipulation is not done in a subversive manner. The salient question (in regards to any photo) is whether or not the photograph is a true and correct image of what was observed at the scene. With radiography, the answer would always be, "No," in that the eye cannot visibly construct an internal image of what is hidden in a large mass of once-molten material.

The manipulation that takes place with DSP is really a form of gathering data that would otherwise be obscured. Moreover, radiography is usually more of a relative investigative tool. If one were investigating to see whether bond wires on an integrated circuit were blown open, an RTR image would show some open and some still intact. The bond wires that are open are easily evaluated relative to the intact wires several hundredths of an inch away. Radiography often is used to compare an image relative to what was expected to be seen.

And we finally note that RTR is a form of NDT (Non Destructive Test); it is often just a preliminary step in a multi-faceted lab exam. Once suitable images are acquired, the data can be analyzed to see if invasive techniques are needed. Often, the RTR is just a tool to see where the investigation may lead. As an example, RTR may show an arced connector inside a resolidified mass of plastics. The RTR preserves how the actual connector appeared before it was eviscerated from the mass; the actual (and best) evidence is the arced connector, and not the RTR image.

EXEMPLAR LIBRARY

One of the attributes of digital imaging is that it is inexpensive and uses no consumables. This makes it very easy to build up a library of digital images of various devices. As examples, our lab routinely examines circuit breakers, TCOs, thermal switches, outlets, and GFIs. A library has been constructed of these undamaged electrical parts. It is relatively easy to compare a 'suspect' part to an undamaged part and then see what salient differences (if any) are present. Photos 8 and 9 show the internal workings of an undamaged (library photo) and a fire damaged Square D brand circuit breaker. Externally, the fire damaged breaker had a handle that had been burned away. The x-rays show internally that the parts are virtually identical.

Along this same line of thinking, RTR makes use of 'differentials;' ie, what are the differences between the exemplar (new) part and the subject part? Are these differences due to an external fire, or is the damage brought on by the part causing the fire? Sometimes the answer is a combination of both.

(Photo 8)
Internal view of a Square D breaker, library image

(Photo 9)
An externally fire damaged breaker, with x-ray showing match to the library image of Photo 8

FOREST FROM THE TREES

RTR has the advantage of allowing one to differentiate between the 'forest and the trees.' As an example, a Printed Circuit Board (PCB) may require analysis. It is somewhat damaged, and has soot, ash, and other products of combustion present. When examined visually, the investigator has a difficult time in discerning what is important and what is not significant. The x-ray energy passes through the fire debris and does an excellent job in presenting only the data from the metal parts, connectors, and components.

SUMMATION

Real Time Radiography offers the forensic engineer a vast improvement over standard film radiographic techniques. While retaining the advantage of a classical NDT technique, it also offers the advantages of rapid thruput, signal processing, magnification, and microfocus. And finally, the digital format allows the images to be easily shared for purposes of collaboration and review. ●

ABOUT THE AUTHORS

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