Federal Working Group on Industrial Digital Radiography

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Hardware for High Energy Applications

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Federal Working Group on Industrial Digital Radiography (FWG-IDR)

The FWG-IDR is a self-chartered organization consisting of federal employees and government contract employees and is endorsed by the Defense Working Group on Nondestructive Testing (DWG-NDT). This working group provides a platform for identifying common concerns and critical issues facing the federal industrial radiographic community as it transitions from film to digital radiography (DR). The FWG-IDR, utilizing expertise from within the community, organizes and coordinates technical committees that formulate postions, guidance, and/or solutions for the community's concerns and issues.

Background

With tremendous advances being made in digital radiography (DR), fueled largely by significant research investments by the medical community, and the acceptance by the general public of digital photography, it has become apparent that digital radiography will have an ever increasing role in industrial radiography. Recognizing the value of DR, many of Federal Radiographic Facilities embracedand implemented the new technology during its earliest developmental stages. Spurred by this expanding use of DR and the recognition that a number of technological and process shortcomings existed, several meetings, attended by Department of Energy (DOE), Department of Defense (DOD), and other government and contractor NDT employees, were held to discuss the future vision for industrial digital radiography in the Federal community. Those meetings became the foundation for the Federal Working Group on Industrial Digital Radiography.

Attendees emerged from those first meetings with a consensus that DR would be the future of industrial radiography, but there were many areas of common concern. They further recognized that a concerted and organized effort was needed to ensure that all issues concerning the transition from old to new technology be addressed. An extensive list of issues were discussed among these nondestruction evaluation (NDE) professionals and several topics were determined to be common amongst the attendees. These common issues were prioritized and task teams established to develop recommendations and guidance for the industrial radiographic community.

Introduction

Conversions to digital technology have picked up considerably in recent years. The year 2009 marked the conversion from analog to digital television signals. Increasing popularity of global positioning systems (GPS) is reducing reliance on paper maps. Doctors can now see x-ray images seconds after they are taken. Information once stored in records rooms is now located on a computer that can be accessed worldwide. Digital cameras allow us to easily process and share photos. The cost of new film and processing can be avoided, while storage area once devoted to developed film is freed for other purposes. With digital imaging tools so widely available and gaining in use, the limits are largely creativity and hard disk capacity.

In the field of industrial radiography, there is a similar trend of digital conversion. Manufacturers are producing computed radiography systems and digital x-ray panels and moving away from film production. However, there are still many questions and issues that need to be addressed.

Purpose

The Federal Working Group on Industrial Digital Radiography (FWG-IDR) identified several transitional hurdles facing the federal industrial radiography community as it moves from film radiography to DR. It was noted that the large majority of the research and development efforts supporting DR were supported by and targeted for the medical industry. The medical community represents a significant market with the industrial community a very distant second. In addition, the medical industry does not have the wide variance in items that it evaluates as it is focused exclusively on examining the human body. As an example, one CT system configuration will suffice in medical examinations whereas the industrial community has to cover a wide scope of inspection items. The DR applications that are most readily implementable are those that closely match the hardware requirements of the medical industry. Transitional issues are problematic in areas where the industrial hardware needs are significantly different from the medical community. There are several general applications areas where this is an issue. However, the most pressing identified need was for hardware applicable to high energy applications. This paper discusses the efforts of the FWG-IDR Task Team for Digital Imaging Hardware for X-Ray Applications and the status of its efforts.

Technology

There are many advantages to consider in digital radiography. The darkroom has been eliminated providing for reduction in chemicals and hazardous waste. The area devoted to film viewing can now be converted to a digital darkroom with computers and high quality monitors. Digital radiography allows for increased dynamic range. Contrast, gamma, and intensity adjustments can provide image presentations that improve decision support and reduce the variability due to operator interpretation. The use of filters and other image processing techniques provide increased flexibility in image analysis. Instead of film storage facilities, hard disks now store millions of digital radiographs. The amount of time it takes to acquire and view an image has decreased. Digital radiography has few consumables and with a few keystrokes, images can easily be transferred for viewing elsewhere. Overall the digital process is much more efficient.

Medical successes have shown that the industrial transition to digital is possible and imminent. However, the medical field does not completely pave the way for the industrial field. Industrial applications differ sharply from medical with its comparatively limited focus on the human body. The following chart illustrates some of the main differences between industrial and medical radiography:

	Medical	**Industrial**
Energy Range	Typically < 200 keV	Part dependent, <10keV to >10 MeV
Density	Limited density range in the inspection object (human body)	Numerous density ranges - Very low (foams, encapsulants, etc.), High (lead, tungsten, uranium, etc.), low density features in the presence of high density structures
Spatial Resolution	Limited spatial resolution needed (> 0.5mm)	Spatial Resolution is part dependent ranging from < 1um to millimeters
Dose Considerations	X-ray dose to object is minimized (typically a few mR for a radiograph)	Some parts are dose sensitive but in many cases it is not a concern
Digital	Majority is DICOM compliant	Majority still film based

There are several different digital radiography technologies that can be used to replace film for high-energy applications.

- Computed Radiography (CR)
- Flat Panel Detectors (Scintillator and Direct Conversion)
- CCD/CMOS Camera Systems
- Linear Diode Arrays

Computed Radiography (CR)

Computed radiography is currently the closest digital technology method to film. When exposed, the plate stores the radiation level received. The plate is then passed through a laser based scanner that causes the plate to output light in proportion to the radiation dose absorbed. This light is detected/measured by photomultiplier tubes. The signal output by the tubes is converted to a digital value at each scan position and these values are combined to form a digital image. The plate can then be erased by exposure to intense light. Figure 1 illustrates the functions of a typical CR system:

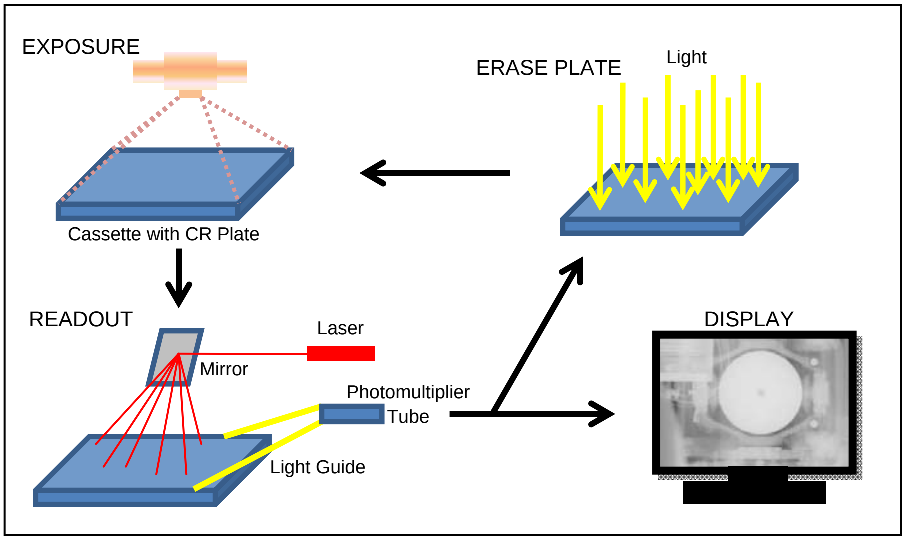

Figure 1: Computed Radiography System

Flat Panel Detectors

Flat panel detectors are area array detectors have the ability to immediately read an image out to a computer screen. An x-ray scintillator is attached to a photodiode/thin film transistor sensor array. The scintillator converts x-ray energy to light and this light is in turn measured by the photodiode sensor array and converted to an electrical signal. The electrical signal is converted to a digital value for each individual pixel on the detector and combined to form a digital image. Figure 2 illustrates the construction of a typical flat panel x-ray detector.

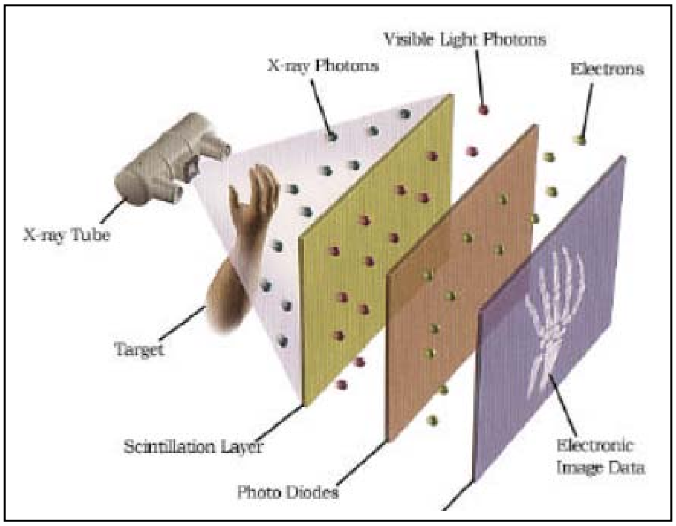

Figure 2: Flat Panel X-ray Detector[1]

CCD/CMOS Camera Systems

Camera systems are typically less expensive but are very effective digital x-ray detectors. There are several system designs using this technology but Figure 3 illustrates the most typical of these setups. The camera box contains a scintillator, turning mirror, and camera. The scintillator converts the x-ray photons to light and a turning mirror then directs this light towards a digital camera. While scientific cameras are recommended, almost any digital camera can be used. The turning mirror is used to avoid direct x-ray exposure to the electronics on the camera. For that reason, it is also important to use beam collimation and camera shielding as well.

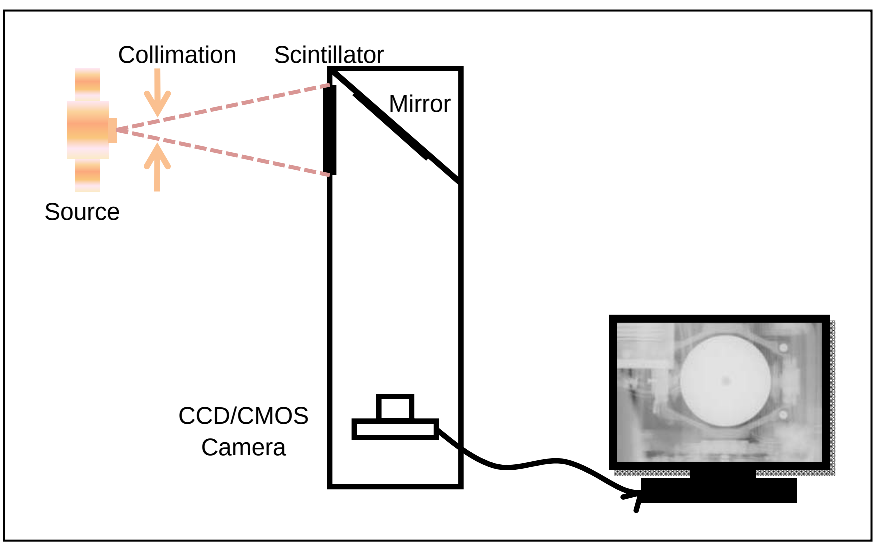

Figure 3: CCD/CMOS Camera System

Linear Diode Arrays (LDA)

Linear diode arrays detectors may not be as efficient at capturing two-dimensional images as the detectors discussed above, but they do provide a very important benefit for certain applications. An LDA is a one-dimensional detectors consisting of a series of evenly spaced photodiodes that are coupled with a scintillator material. Collimation limits the x-ray beam to a small slit. The object being inspected can be translated up or down through the x-ray beam to acquire a two-dimensional radiograph. Each line can then be stitched together to create an image. Linear diode arrays are primarily beneficial for computed tomography applications, situations where it is necessary to reduce the amount of x-ray scatter imaged from the part, and applications synchronized with a motion system like production lines.

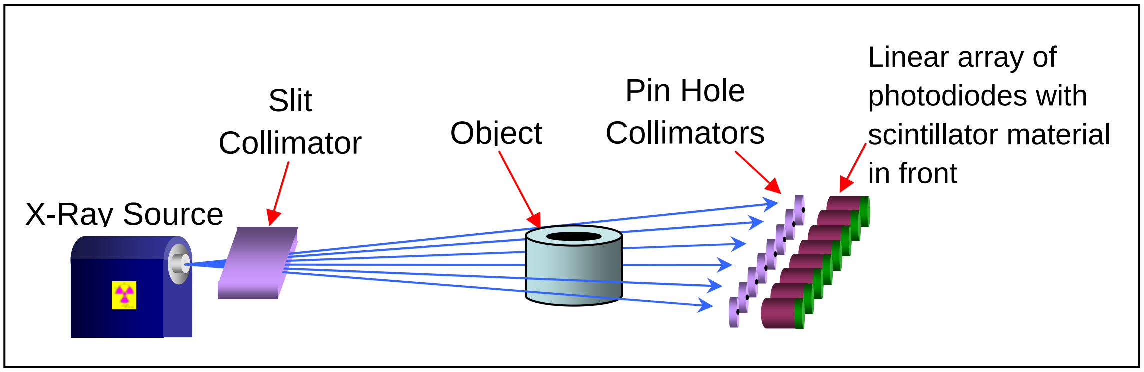

Figure 5: LDA System

Cost Comparison

Digital radiography can provide tremendous cost savings. It is no longer necessary to buy film developer chemicals and deal with the waste it yields. Large packs of film and the refrigerator space needed store them are replaced with a handful of computed radiography plates or a digital detector. The footprint of a digital system is small compared to a darkroom. Envision Product Design, a supplier of LDA's and CMOS detectors, provided the following estimate in savings for converting to digital[2].

Digital Solution	Film Radiography
Space Cost (Computer Workstation) 10 sq. feet $20/month	Space Cost (dark room, processor, illuminator, film storage, chemical storage, plumbing electrical, janitorial, etc.) 300+ sq. feet $500/month
Equipment (Digital x-ray detector) Overall cost $102,375 Amortized over 5 years $1706/month	Equipment (film processor, dark room, etc.) Overall cost $66,420 Amortized over 5 years $1107/month
Re-occurring Costs per 1000 exposures 1 CD-R disk 10 cents	Re-occurring Costs per 1000 exposures Film, chemicals, waste disposal, processor maintenance, etc. $6000

Envision says that 'when switching from film to digital many users will recover their investment within four to five months and the savings can begin at the rate of over $10,000 per month per system.' Although this cost estimate is not applicable to all radiographic operations, it is clear that the conversion from film to digital operations provides significant cost advantage. The initial cost of converting to digital may seem steep but the recovery time can be relatively short.

Future Development

The consensus among most government agencies in the FWG-IDR is that the most pressing issue is the performance of digital imaging products at high energies. For the purpose of this discussion, high energy is defined as any source that operates above 450 keV. The following bullets illustrate some of the shortcomings of the technologies discussed above.

Computed Radiography

- Spatial resolution still lower than film
- Image latency in imaging plates
- Plates are susceptible to damage
- Cost to replace damaged plates ~$200 compared to $10 per sheet of film

Flat Panel Detectors

- Susceptible to radiation damage above 200kV
- Internal scatter limits dynamic range and spatial resolution (this becomes more of an issue as x-ray energy increases)
- As the field of view increases, the spatial resolution decreases
- Repairs can be costly and take a considerable amount of time
- Rigid form factor
- Scintillators can limit
    - Capture efficiency
    - Spatial resolution
    - Light output
    - Image latency / light decay

CCD/CMOS Camera Systems

- As the field of view increases, the spatial resolution decreases
- Capture efficiency is a function of how close the scintillator is to the sensor (among other factors), in turn affecting the field of view
- Camera sensors are very sensitive to x-ray exposure
- Scintillators used with the cameras can limit
    - Capture efficiency
    - Spatial resolution
    - Light output
    - Image latency / light decay

Linear Diode Arrays

- Small field of view because the detector is one-dimensional
- Slow data acquisition
- Scintillator material limitations
- Low spatial resolution

Scintillators

Improved scintillators with better conversion efficiencies for higher energies and higher resolution would have a significant impact on the industrial community's ability to fully implement digital radiography. These high energy scintillators coupled with higher resolution digital detectors hardened for high energy applications would provide the industrial communities with the tools they need to fully implement digital radiography.

Conclusion

Many government agencies currently utilize the digital radiography technologies discussed in this paper. However, none of these technologies has become a complete replacement for film. For that reason, many film processes are still in use, and will continue to be until these issues are addressed.

As industry moves forward in converting to digital radiography, the need to prioritize and resolve the issues discussed above becomes crucial. Communication among groups performing research and development is important to ensure collaboration when practical. While this paper has been developed by a group representing the government and prime contractors, the desire to make improvements is transcendent. Advancements through MANTECHs, CRADAs, SBIRs, commercial investment, and other funding sources are all necessary avenues that must be explored.

While the initial efforts of the FWGIDR are focused on higher energies, these improvements will certainly benefit radiography at all energies. As with any new technology, digital radiography has room to grow, but timely consideration of these issues can make the conversion to digital x-ray a more seamless transition.

References:

1. Varian Security and Inspection Products, “PaxScan Flat Panel X-Ray Imaging” http://www.varian.com/media/xray/products/pdf/Flat%20Panel%20Xray%20Imaging%2011-11-04.pdf

2. Envision Product Design, http://www.cmosxray.com/Documents/costcomparison.shtml