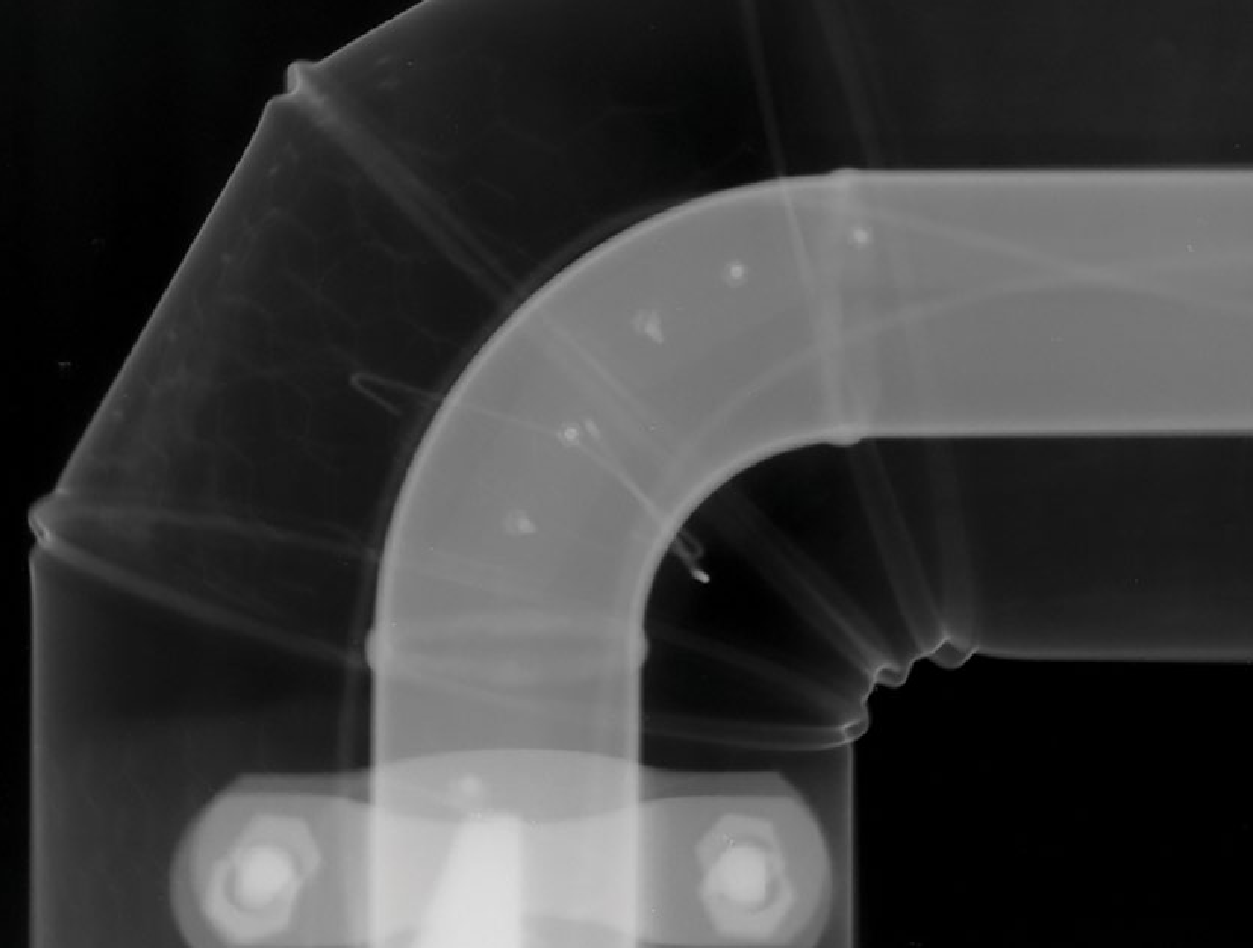

UNDERSTANDING THE CURRENT CAPABILITIES AND LIMITATIONS OF DIGITAL INDUSTRIAL RADIOGRAPHY

A DISCUSSION REGARDING THE CURRENT STATE OF THE TECHNOLOGY AND THE REASONS BEHIND THE SLOW TRANSITION FROM FILM TO DIGITAL RADIOGRAPHY

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ABSTRACT

In 2017, SGS conducted market research on the use of digital industrial radiography, inviting end-users in more than a dozen countries to take part in a survey. This document looks at the subject, its definition, current state of the technology, capabilities, and more importantly, its drawbacks. The key findings of the survey were also reviewed and the document aims to provide insight to the reasons for the slow transition from film to digital industrial radiography.

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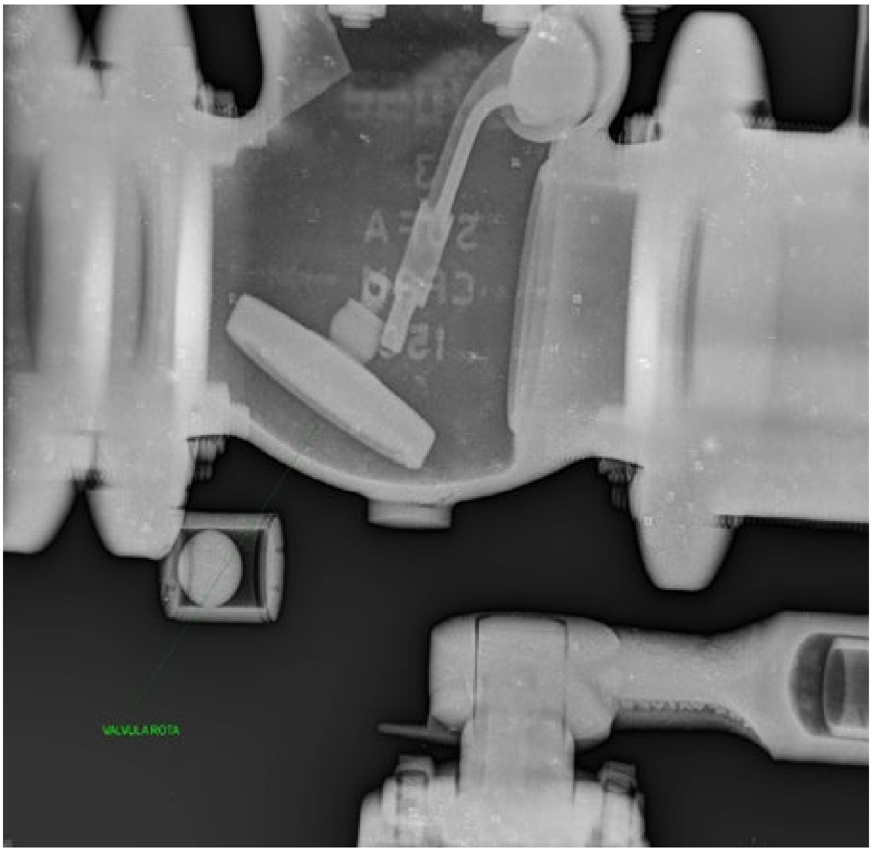
I. EXECUTIVE SUMMARY

Compared to film, digital industrial radiography can be considered, in general terms, as safer, as it requires less radiation; being greener in its operation, as it needs no chemicals, or consumables. It is also faster in terms of processing, as there is no need for development, and fewer retakes are needed thanks to the wide dynamic range of CR imaging plates and DR flat panels, which can be used repeatedly. This also tends to reduce the operational costs. However, this does not always hold true, as the number of times an imaging plate can be reused will depend on multiple factors, for example, the type of application, the environment where the work is performed and the care with which the plates or DR panels are handled.

The advantages of digital radiography don't stop there. Being able to produce a digital file that can be analysed, stored, and shared with ease, is a strength that has not yet been fully exploited. The potential for remote image interpretation and evaluation, and more importantly, assisted or automated defect recognition (ADR), are some of the most significant benefits this technology brings to the market.

Despite all the features and advantages CR and DR have over film, there are some weaknesses and hurdles that must be overcome before the accelerated transition from film to digital radiography can occur. Among them, are a few that are linked to the technology, such as image resolution, which is still not as high as that achievable with fine grain film. There are also other obstacles that are more closely linked to the acceptance of this technique through codes, standards, and regulations, as well as by end-users.

Film radiography is one of NDT's most basic testing methods, and has been continuously developed over a period of more than a hundred years. Today, film radiography has clear standards that are widely accepted for its use in a variety of applications. These codes not only cover the correct application of the method, but also the training and competency required to qualify the personnel that will conduct the work, an area where CR/DR is lagging behind. Some industries and authorities still need proof that digital radiography and the evaluation of digital images are equivalent to the results obtained with film radiography.



Great advances have been achieved over the last 12 years in the development of standards for digital radiography. Today, ASTM, ASME, EN, and ISO have included digital RT as an accepted NDT technique, allowing its use for a variety of applications, including the inspection of welds in pipes, plates and vessels, castings and the evaluation of corrosion and erosion in tubes and pipes, for example. However, there are other applications where codes and standards are yet to allow the use of digital radiography. Digital RT does have limitations in its use. With the technology available today, large diameter, thick walled or liquid filled pipe, are applications where digital RT would not bring any improvement over film radiography.

Finally, concerning the future of film, and whether it will one day be completely replaced by digital RT, it is believed that the technology will continue to improve, and that technological obstacles will eventually be overcome. Codes and standards will be developed where they are missing, and training programmes will progressively get better. Thus, the transition is inevitable and is likely to accelerate, especially as equipment prices come down and training becomes widely available and affordable. There will certainly be a few niche applications or small-scale projects where film remains more cost effective but by then, the bulk of industrial radiography will have become digital.

II. DIGITAL RADIOGRAPHY

FILM RADIOGRAPHY (RT)

Conventional radiography uses film to capture the image. That is, the radiation used passes through the object of interest exposing the film, which is held in a light-tight cassette, to the radiation not stopped by the object. A latent image is created on the film that can be revealed by processing in a darkroom. The resulting image is a physical item that can be viewed in the film with the use of a light box viewer. It is worth noting that the image on the film is made of silver halides and the excess silver is removed during the film processing. Silver itself is a heavy metal element.

COMPUTED RADIOGRAPHY (CR)

With CR the film is replaced with a flexible Image Plate (IP) which is coated with a phosphor layer. The radiography is carried out in the same way as with film, with the IP inside a light-tight cassette. Once exposed, the IP is returned to a darkened area for processing.

To process the IP, it is placed into a scanner, where a focused laser beam is used to trigger the phosphor layer to emit light, the amount of light emitted being directly proportional to the quantity of radiation that the IP was exposed to. The emitted light is detected and converted to a digital signal. The digital signals can then be displayed via a monitor as a raw image. Subsequent processing of that image can allow the operator to view the data captured and manipulate it to produce the best image of the object or area of interest. This image can then be annotated, stored and exported. The raw data is also stored unaltered for future reference.

After processing, the system can wipe the IP clear so it can be re-used.

DIRECT RADIOGRAPHY (DR)

DR uses a Flat Panel Detector (FPD) to capture the image instead of a film or IP. The incidental radiation creates a digital signal either indirectly, via a scintillator that emits light when exposed to radiation (this is detected by a photosensitive diode layer) and a digital signal is produced, or directly where the FPD converts the incident radiation to a charge pattern.

The raw data is displayed instantaneously on the viewing computer system, allowing control of the exposure live on the system. Once the image is captured it can be manipulated to produce the best image of the object or area of interest. This image can then be annotated, stored and exported. The raw data is also stored unaltered for future reference.

Figure 1 shows the three different systems (film, CR, DR). Note that for film radiography, an automatic film processor can be used instead of manually developing the film.

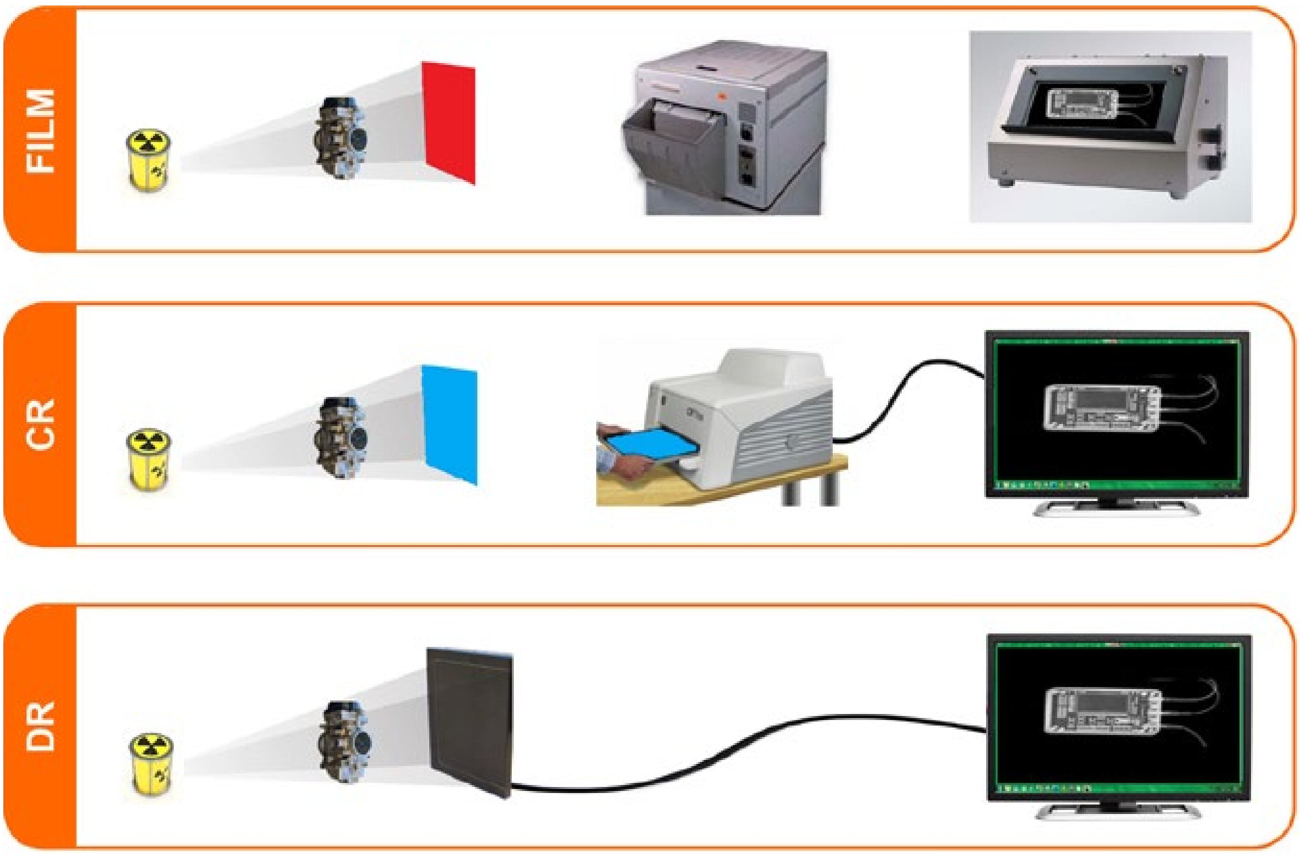


Figure 1

III. FILM VS. DIGITAL

Film radiography is a well-established process with numerous codes and standards covering all aspects of its application and quality control. The physical production of radiographs, subsequent processing, and interpretation of the results have well developed, and widely available, training courses, qualifications, and a large pool of experienced technicians.

CR and DR have only recently started to be recognized in codes and standards for their applications. As there are a variety of systems from multiple manufacturers, training is only relevant to the particular system the training is for, thereby limiting the pool of technicians that can be considered as experienced on anything but a single system. Qualifications exist but are tied to particular technologies or systems due to the differences in operation.

CR IP's can be exposed by a radiographer who has been trained in film radiography with just an exposure adjustment. The processing and image interpretation, however, requires specific training. The operation of DR systems, on the other hand, require additional training of the radiographer as the image is captured directly and requires monitoring during the exposure.

IV. CURRENT LIMITATIONS OF DIGITAL

The best way of comprehending the limitations of digital industrial radiography is by recognizing the strengths and weaknesses of what it is trying to replace, i.e. film radiography. Film radiography is a widely used NDT method which has been in use for almost a century and for which we have a clear understanding of its advantages and disadvantages. Film radiography's key strength is its high-resolution images, but to achieve this level of image quality it requires film processing facilities, and considerable time to develop and interpret the film. Film development also exposes people and the environment to hazardous chemicals and heavy metals. The other disadvantage of film is that it is not reusable and it requires resources to store and retrieve, and inadequate storage practices will result in premature deterioration of the radiographic film.

Digital radiographic systems solve many of above mentioned issues, eliminating the film development process in the case of DR, and replacing film development with IP scanning for CR systems. Once the images have been converted into electronic files, storage, retrieval, and sharing can be done at a very low cost, in an easy and efficient way. However, the main advantage of film, its image quality and primarily its high resolution, has yet to be matched by digital systems.

Image quality is a complex topic and encompasses many elements. However, image resolution, ultimately determines the quality of the digital radiograph. Image resolution involves three key parameters. The first is quite intuitive and well understood by the layman thanks to the ubiquitous use of digital photography, and has to do with the number of pixels, or more importantly, the pixel size. Not only the pixel size of the detector (DDA) or the pixel size produced by scanning an IP or digitizing a film radiograph, but also as important is the pixel size of the display screen that will be utilized to view and interpret the image. The display station resolution must be as good as, or better than, the resolution of the image file.

The second parameter of image resolution is related to the number of grey levels or what is also called bit depth, which is the number of bits used to define each pixel. The greater the bit depth, the greater the grey levels that can be represented. This will also have a direct effect on the sharpness of the image, that is, the ability to represent in the form of the image contrast the actual object contrast as a variation of spatial frequency.

The third parameter affecting the overall quality and therefore sensitivity of an image is the noise within it, be that the absolute noise or the Signal-to-Noise Ratio (SNR). As systems become more sensitive they also tend to produce more noise, that is, unwanted signals generated by the electronics of the system, or external factors other than those relevant to the image, i.e. other wavelengths of radiation. All systems will have methods of filtering the signal to reduce absolute noise and improve the SNR to an acceptable level but this can also have the effect of reducing the sensitivity of the image to small or fine indications. Other filters, smoothing and extrapolation, designed to improve the image, may also have a reducing effect on ultimate sensitivity to indications.

The three factors that define image quality can be better understood by looking at the pictures in figure 2. The pictures on the top row have different resolutions, with the middle picture having a 16x greater resolution than the left-hand side picture, and 16x lesser resolution than the right-hand side one. The pictures in the middle row have different number of grey levels, and the pictures in the bottom row have different Signal-to-Noise ratios.

Although image quality is one of the biggest limitations today, it is not the only one. The geometry of the products to be inspected can also be a problem, especially for DDA panels which are not flexible and thus far are only commercially available in a flat format. The inspection of welds in large diameter pipes (e.g. pipelines) with a relatively small flat panel is not the most effective way of doing the work from a cost perspective.

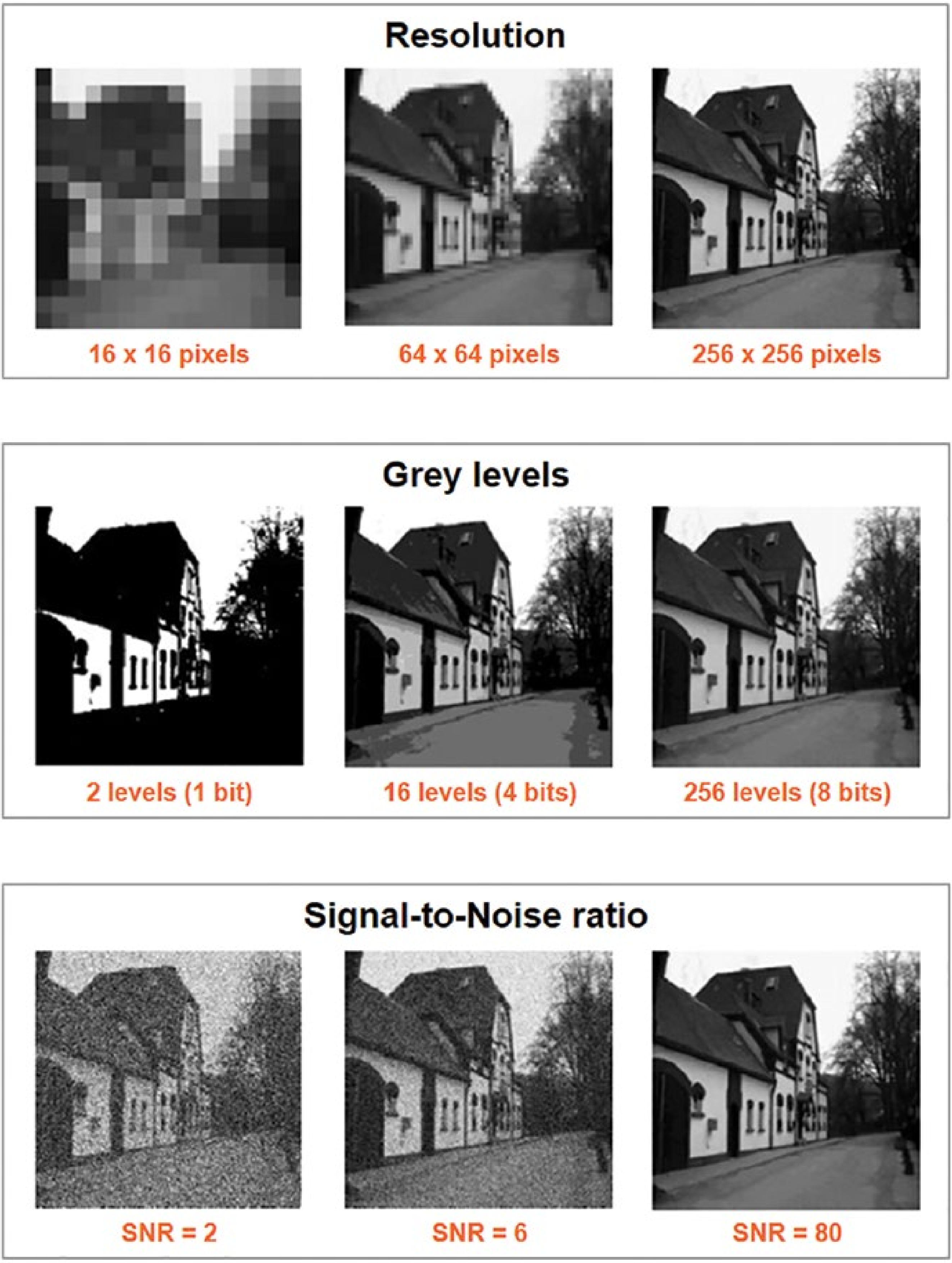

Resolution
16 x 16 pixels
64 x 64 pixels
256 x 256 pixels
Grey levels
2 levels (1 bit)
16 levels (4 bits)
256 levels (8 bits)
Signal-to-Noise ratio
SNR = 2
SNR = 6
SNR = 80

Figure 2

V. WILL THE FUTURE BE ALL DIGITAL?

The answer is probably yes, but the real question is when will this happen, and the answer to that is a lot more difficult to predict. In the previous sections we have discussed current limitations and technical challenges of CR and DR systems, as well as the relatively slow progress of the development and acceptance of codes and standards. However, there is another issue that is holding back the pace of change from film to digital, and that concerns the cost of digital systems. Digital systems are similar to film radiography, in that a radiation source is required, but everything after exposure is different. In the case of CR systems, imaging plates and a scanner are required to produce the digital image, and a computer workstation is needed to visualize and interpret the image. One imaging plate can cost >100x the equivalent size of film and a scanner costs between USD 40,000 – 140,000. A computer workstation, which includes a high-resolution screen and software, can cost USD 45,000. With a DR system, it is only the DDA panel and the computer workstation which can cost between USD 100,000 – 150,000. So, while film radiography has a relatively low initial cost, CR and DR systems require a significant upfront investment, and the return on it will greatly depend on the volume of images per year that can be processed. This is currently one of the key reasons for the slow conversion from film to digital system.

Manufacturers and suppliers of digital systems present curves showing a theoretical payback period based on the number of images per year required, and making ideal assumptions on the number of times imaging plates (in the case of CR) will be reused. Unfortunately, imaging plates must be handled in the field under all types of weather and environmental conditions, and the slightest scratch can make them unusable. Additionally, the actual number and size of the imaging plates required for a specific job can make it uneconomical to use CR in replacement of film. DR panels would seem to be the solution, but once again it is the conditions and requirements of individual jobs that don't allow them to be cost-effective all the time, and the consequence of damaging a DDA panel can wipe out all potential savings. Furthermore, the physical requirements of the job may also preclude the use of DR altogether.

Figure 3 shows a sensitivity analysis on the cost per image with a DR system based on the average utilization rate of the unit. According to analysis based on actual data for an ongoing operation, an average utilization rate of about 60% is needed to match the cost per image for film radiography, and a utilization of around 80% would be required to achieve a reduction of 10% in the cost per image. For countries with lower labour rates, the utilisation rate needed to achieve a 10% reduction in cost, compared to film radiography, will be higher.

However, the future is already here for two main types of application, one being production line radiography, where DDA panels remain fixed in one position, shooting hundreds of images per day. The other is the inspection of pipes for corrosion damage. This only requires a flat plate and maximizes the benefits of CR/DR by exploiting the massively increased latitude of images produced by CR/DR. That is the increased image data for different thicknesses and radiation absorption factors. The built-in measuring tools also make the quantification and highlighting of damage levels easier and more effective. See Figure 4.

Another type of application where CR and DR are becoming increasingly available is laboratory environment industrial radiography (also known as bunker X-ray) work, where the imaging plates, scanners, DDA panels, and computer workstations remain in a relatively low-risk and controlled environment, minimizing damages, and maximizing utilization.

Field radiography applications, however, are the bulk of industrial radiography, particularly for new construction applications. Nevertheless, the replacement of film with digital systems has been taking place, and in recent years the pace of change has accelerated. In the last three years the use of digital RT, and primarily CR systems, has almost doubled, bringing the share of digital RT today to more than 10% of the total output of industrial radiography.

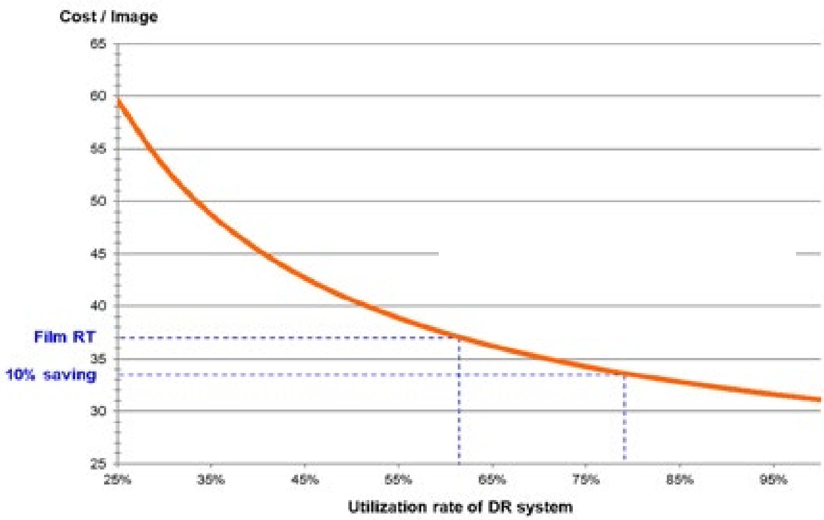


Figure 3

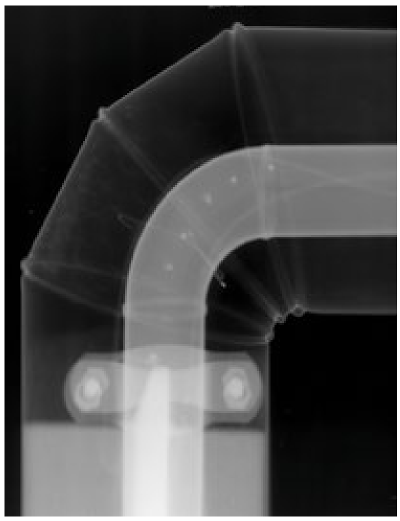


Figure 4

VI. CONCLUSIONS

The march towards CR and DR replacing film may be inevitable in the long run, mirroring the almost complete change from film to digital in the photographic market. In the short term however, the principal obstacles are:

- Capabilities of the technology: until CR and DR can produce images that not only meet the standards and codes but also allow the detection of all the defects that film can, there will always be some reluctance in the market to accept its use for all applications.
- Cost of establishing a system: unless a service provider can gain tangible benefits from using CR or DR, they will not consider making the high investment of acquiring the technology, particularly, if they can't fully replace the use of film, as it then becomes an additional cost to maintain both techniques, rather than an offset replacement cost.
- Status quo: many established radiography end-users, such as the oil and gas industry, are often slow to accept new technologies. Due to the high-risk environments in which they operate there is a tendency to avoid changes, and continue to use what is known to work. That said, the low oil price environment that started at the end of 2014 is putting pressure on operators and forcing them to find innovative and more efficient ways of doing things.
- Obsolescence: NDT service providers and end-users open to new technologies who became early adopters of digital radiography, may have purchased systems that are not as technically advanced as those currently available. If the systems acquired did not prove to be as effective as expected, these users may become reluctant to further invest in newer technology until the market prices match perceived value.

Notwithstanding the above-mentioned obstacles, it is expected that once a service provider or customer successfully uses either CR or DR in a major project or specific application, and experiences firsthand the advantages of the technology, then the rest of the market will rapidly follow. The manufacturers, service providers, and end-users leading this transition will then enjoy a significant advantage over their competition.

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