Increase of productivity by using digital radiography

K. Lovòn, D. Schlösser, YXLON
P. De Soete, R. Perret, AREVA NDE-Solutions France - Intercontrole
C. Schlösser, Universität Hamburg

1 Abstract
Radiographic X-ray film has been used for the inspection of aerospace parts during several decades. As the film properties are well known the results were reproducible, but the film handling, processing and archiving is slow and costly. Changing from film to digital detectors is a two-step process. First the parameters for the image acquisition need to be re-defined and image quality need to be determined (signal-to-noise ratio, spatial resolution, contrast sensitivity...). In the second step the part handling needs to be optimized in order to reduce the inspection time and to create a reliable and safe process assuring the proper part identification and tracing, the inspection, the evaluation of the results as well as the archiving of the results. A high degree of automation assures both a reliable image acquisition and image processing. Several examples how both steps of the process can be implemented successfully will be given.

2 Résumé
Le film radiographique a été utilisé pour l'inspection de pièces aéronautiques pendant plusieurs décennies. Comme les propriétés de film sont bien connues les résultats étaient reproduibles, mais la manutention du film, le traitement et l'archivage sont lents et coûteux. Le changement du film aux détecteurs numériques est un processus à deux étapes. D'abord les paramètres pour l'acquisition d'image doivent être redéfinis et la qualité d'image doit être déterminée (le rapport signal/bruit, la résolution spatiale, la sensibilité du contraste ...). La seconde étape est l'optimisation de la manipulation de la pièce pour réduire le temps d'inspection et créer un processus fiable et sûr assurant l'identification des pièces appropriée et la traçabilité de l'inspection, l'évaluation ainsi que l'archivage des résultats. L'automatisation assure l'accquisition et un traitement d'images fiable. On donnera plusieurs exemples montrant comment les deux étapes du processus peuvent être mises en œuvre avec succès.

3 Introduction
About ten years ago digital detector arrays (DDA, sometimes also called "flat panel detectors") offered new opportunities for the acquisition of digital X-ray images. The two different techniques that were used before had significant disadvantages. Industrial X-ray films are slow and need an extensive amount of chemistry while in many cases image intensifiers did not comply with the high image quality requirements in the aerospace industry.

Although the DDAs provide an excellent image quality, some standards and procedures had to be developed in order to allow the use of DDA in the aerospace industry [1, 2, 3].

4 Image processing
The X-ray images that are acquired with DDAs possess a dynamic range up to 16 bit, i.e. up to about 65000 gray values. Most monitors are able to display only 256 different gray values and the human eye can resolve typically less than 100 gray values. So the images need to be scaled so that the operator is able to analyze the image. After this scaling process some
areas of the image may be easy to evaluate, while others are too dark or too light. To alert the operators some image processing systems [6] mark these areas with colors, so that the operator is immediately informed about the areas where an evaluation is not possible (see Fig. 1).

![Scaling of the X-ray image](image.png)

**Fig. 1: Scaling of the X-ray image**  
Areas not showing any information after scaling are marked in blue or red

Due to the limits of this simple scaling a more advanced image processing is required to allow the operator, who evaluates the X-ray image, to determine the quality of the test part in more detail. This advanced image processes consist of digital filters that help to bring out the anomalies or other interesting structures of the test part. The detailed techniques of the digital filters are described elsewhere [4]. In many cases the effective wall thickness of the parts to be inspected varies significantly thus leading to very different gray values. Without digital filters the operator would need to change contrast and brightness again and again in order to evaluate all areas of the test part.
Fig. 2: X-ray image of a turbine blade

Fig. 2 shows an easier and more reliable way: The X-ray image is filtered leading to a reduction of the large scale gray value variances (due to different wall thicknesses) and thus to an easy recognition of the small crack at the top of the blade. Recently a filtering of even live images has been developed [5] taking into account that the human eye is very capable in detecting discontinuities in a slowly moving part.

In order to meet the required specification it is not only essential to generate X-ray images with the necessary quality parameters, it is also crucial to determine the image quality itself. The ASTM E2737 “Practice For DDA Performance Evaluation and Long-Term Stability” describes in detail the procedures for the initial and the regular approval of the imaging chain. High end image processing software [6] allows such an evaluation by providing tools e. g. for the determination of the spatial resolution according to EN 462-5.
The lower part of Fig. 3 shows an X-ray image of the duplex wire gauge described also in EN 462-5. In many cases the operator determines visually the thinnest wire pair he is able to resolve. It is clear that this judgment is somehow subjectively biased and different operators come to different results. Fig. 3 illustrates the semi-automatic evaluation of the duplex pattern. In the X-ray image the operator just draws a line perpendicular to the duplex wires in order to obtain a gray value profile along this line (shown in the upper part of Fig. 3). In order to improve the signal-to-noise ratio of the gray value profile the operator can increase the width of the line, to a value of e.g. 170 pixels as shown in this example. The line profile shows then the double peaks of the duplex wires and the software determines automatically, which wire pair can be resolved. The result can be stored for documentation purposes and does practically not depend on the operator.

Another important parameter of the image quality is the contrast-to-noise ratio $CNR$. This value is not directly accessible to an operator and only an image processing system allows to calculate it by using the following equation.

$$CNR = \left| \frac{S_A - S_B}{\sigma_0} \right| = |SNR_A - SNR_B|$$

where $S_A$ and $S_B$ are signal intensities for the different image areas A and B (e.g. in the case of an IQI according to ASTM 1025 the areas with and without hole) and $\sigma_0$ is the standard deviation present in the image.
Fig. 4: ASTM E1025 IQI with 2T and 1T hole; automatic evaluation of the contrast-to-noise ratio

Fig. 4 illustrates how the image processing software measures the CNR and determines thus the visibility of the penetrant holes in comparison to the noise of the area around the holes by using an IQI penetrant manufactured to the ASTM standards E1025 or E1742. Before carrying out a contrast sensitivity test the operator defines a region of interest (ROI) that encloses both the 2T and the 1T hole, followed by a click into the 2T hole. The software calculates the SNR distances and the test result is displayed in a special SNR distance dialog box. The results of the 2T hole are shown in the left column of the dialog box and the results of the 1T hole in the right column. The two "Mean" fields show the average local SNR of the entire ROI image for the size of the 2T and 1T holes.

The calculated results are displayed in the bottom section of the dialog. If the results are within the specification that was defined before, the final test result is OK. Due to this automated procedure the operator can be sure of the CNR without any influence of subjective factors.

In addition to the 2D radiographic images computed tomography (CT) offers full 3D information of test parts. Fig. 5 shows some sample images of turbine blades. For the void analysis as well as for the determination of wall thicknesses CT offers by far more possibilities compared to DR.
A couple of years ago CT was used mainly in R&D, due to a number of reasons. First the image acquisition and reconstruction time were quite long. Second the set-up of the test part required a lot of manual work and finally the interpretation of the images was quite complex. New techniques have now reduced these disadvantages, so that CT is more and more used also in the production.

Standard X-ray inspection systems as the Y.Multiplex [7] allow to combine a standard DR inspection with CT. So one inspection sequence contains e. g. a couple of DR images and one or more CT scans of some dedicated zones. Depending on the required quality the operator chooses a QualityScan© or a QuickScan©.

Fig. 6 QualityScan© of a cast aluminum part, scan time 5 min

Fig. 6 shows a QualityScan© of a cast aluminum part with 1440 projections. The pixel size of the DDA was 200 µm and the reconstructed volume consists of 512³ voxels. As the image acquisition takes 5 min the small voids can be identified easily. When using a QuickScan© as demonstrated in Fig. 7 the image quality is somehow reduced, but still sufficient for many purposes. Please note that the image acquisition time has been reduced to 18 s, thus enabling the CT scan to be part of a standard DR inspection cycle.
Not only the scan itself, but also the evaluation can be automated easily. Fig. 8 shows how a cross section at a pre-defined position is displayed followed by a quantitative evaluation of a porosity.

So modern X-ray systems enable to set-up an inspection cycle with a well defined and reliable image acquisition. Additionally, the evaluation of the X-ray images can already be improved: The software provides the images in a way that enable a safe and reliable evaluation. Therefore the use of DDAs lead to a higher quality of the evaluation process itself.

5 Summary
The modern components like DDAs and image processing system lead to an outstanding image quality of the X-ray images that could not be achieved before. However, not only the image quality is crucial, but also the measurement of the image quality in order to make the inspection process safe and reliable. Therefore it is absolutely necessary to determine and to proof the different image quality parameters and to document them.
Furthermore the integration of CT scans into automated test cycles with well defined inspection parameters allow an even more detailed analysis and contribute further to a more consistent and trustworthy inspection.
6 References


3 Standards of the ASTM E2736, E2698, E2737, E2597


5 http://www.hdr-inspect.com/
