AUTOMATING THE X-RAY INSPECTION

Frank HEROLD, Peter KRAMM and Uwe ADAMCZAK,
YXLON INTERNATIONAL, Hamburg, Germany

Abstract

Each part to be inspected (e.g. castings, tubes, composites etc.) leads to its own specific requirements concerning quality assurance. The requirements mainly depend on the fields of application and whether the test parts are used under safety-critical conditions.

Third generation X-Ray inspection systems [9] are well known as robust and reliable fully automated defect recognitions systems (ADR systems) for many different test parts. Such systems have become the standard for X-Ray based non-destructive testing (NDT). For aluminum castings they are mandatory particularly in the automotive industry for safety-critical parts like wheels, 'knuckles', pistons etc.
But even in the aviation technology X-Ray inspection replaces and outpaces the classical film based inspection by using high-quality digital flat panel detectors [2]. Digital image processing software-algorithms similar to the algorithms of ADR systems will also arise as the methods of choice in such applications.

Nevertheless a huge variety of parts to be inspected exits that is not suitable to be inspected in a batch process. Prototypes, small series or even a series of unique parts for example are still inspected visually and not by ADR.
Modern fully automated as well as visual digital X-Ray inspection systems are well-equipped by a high-power X-Ray tube (e.g. with variable focal spot size) and a high-performance digital flat panel detector that provides spatial resolutions up to 200µm and 30Hz per full-frame. Today, the dedicated manipulator systems perform fast and precise movement of the test parts. These manipulators are also controlled digitally by software.

Therefore the human user is able to adjust and control the X-Ray, the imaging as well as the mechanical manipulator system through only one user-friendly graphical interface by software.

Most of the adjustments that a human user has to apply in state-of-art X-Ray inspection systems are not necessary due to the digital control of the system.

Automating the X-Ray inspection will save costs and will help the human inspector to concentrate on NDT and not on adjusting his inspection system.

The following items are evaluated to demonstrate the potential of automating the X-Ray inspection:

- System qualification is used to ensure a reliable imaging system providing constant image quality for a long term automatically by using methods in compliance to EN 462-5 (platinum duplex wire) or ASTM E 1025 / E 1742 (penetrameters with 1T and 2T holes).
- Automatic gray-scaling [8] to visualize the most important image information to the human inspector.
- High dynamic radioscopy (HDR) [1, 4] to enhance the structural details of a test part.
- Fully automated detector calibration to get for each application the best image quality (see [2]). In modern X-Ray inspection systems the power of the X-Ray source and the manipulator positioning the calibration object are controlled automatically without any user-interaction during the calibration process. Depending on the currently set system parameters,

the software will choose the best fitting calibration data-set to ensure always an excellent image quality.
- Automatic X-Ray control to adjust the optimal dose of the X-Ray source depending on the appropriable signal range of the dedicated imaging detector.
- Automatic background segmentation. ADR-Systems are fully automated concerning the batch testing [9], but still intelligent image processing algorithms [8, 10] are needed for some few adjustments, e.g. defining regions inside an image of the part.

This article will show how to benefit from the manifold possibilities of controlling the X-Ray, the imaging and the mechanical manipulator system digitally and automatically by software. Intelligent image processing algorithms are able to ease the needed adjustments of an X-Ray inspection system. As conclusion the performance and today's possibilities are summarized and an outlook for further development is given.

Introduction

Automating the X-Ray inspection saves costs and will help the human inspector to concentrate on NDT and not on adjusting his inspection system.

Up to now Automation often has been associated with the third generation of Automatic-Defect-Recognition-Systems or short ADR-Systems. Such systems have become the standard for X-Ray based non-destructive testing (NDT). Particularly in the automotive industry X-Ray inspection systems are mandatory for safety-critical parts like wheels, 'knuckles', pistons etc.

For example in the automotive market for smaller batches, sampling inspection or even prototypes visual X-Ray inspection systems have still an amount of over 50%, i.e. also in the field of visual inspection Automation is needed or improves the speed and reliability of the inspection process that is still supervised by the human inspector.

In the aerospace industry often X-Ray films are still used, but due to the new digital image processing hardware and software the film will be replaced in the next years. On this market nearly all used X-Ray inspection systems for quality assurance are visual systems.

The inspection of welds, tubes or high-tech materials like composites are further examples of fields of application for visual X-Ray inspection systems that are supervised by an human inspector.

Modern fully automated as well as visual digital X-Ray inspection systems are well-equipped by an high-power X-Ray tube (e.g. with variable focal spot size) and an high-performance digital flat panel detector that provides spatial resolutions up to 200µm and 30Hz per full-frame. Today, the dedicated manipulator systems perform fast and precise movement of the test parts. These manipulators are also controlled digitally by software.

Therefore the human user is able to adjust and control the X-Ray, the imaging as well as the mechanical manipulator system through only one user-friendly graphical interface by software.

Most of the adjustments that an human user has to apply in state-of-art X-Ray inspection systems, mainly in visual, but also in ADR systems, are not only time consuming, they are due to the digital control of the system not necessary.

In the sense of image processing these modern techniques provide a significantly improved image quality in comparison to image intensifiers or even films including Computed Radiography (CR). The time consuming adjustments of X-Ray and image processing parameters can be automated taking advantage of the increased computation performance of general purpose PCs and the use of

algorithms for intelligent X-Ray image analysis using the feedback between imaging source and X-Ray control or manipulator.
Imaging software is generally deterministic, i.e. the human inspector gets optimal image quality and objective indications in a reproducible manner.

In the following sections we will introduce selected use cases visualizing the automation potential concerning the visual X-Ray inspection systems.

Automating System Qualification

The image quality of modern flat panel detectors designed for industrial usage is characterized by certain parameters released as ASTM standard E 2597-07. Depending on their actual field of application and the dedicated inspection task a proper detector type has to be chosen. A so-called spider-net diagram visualizes the mentioned detector parameters to find easily the appropriate detector. Figure 1 shows a spider-net diagram of a Perkin Elmer flat panel detector as an example for a high-quality detector with a spatial resolution of 200 µm [3].

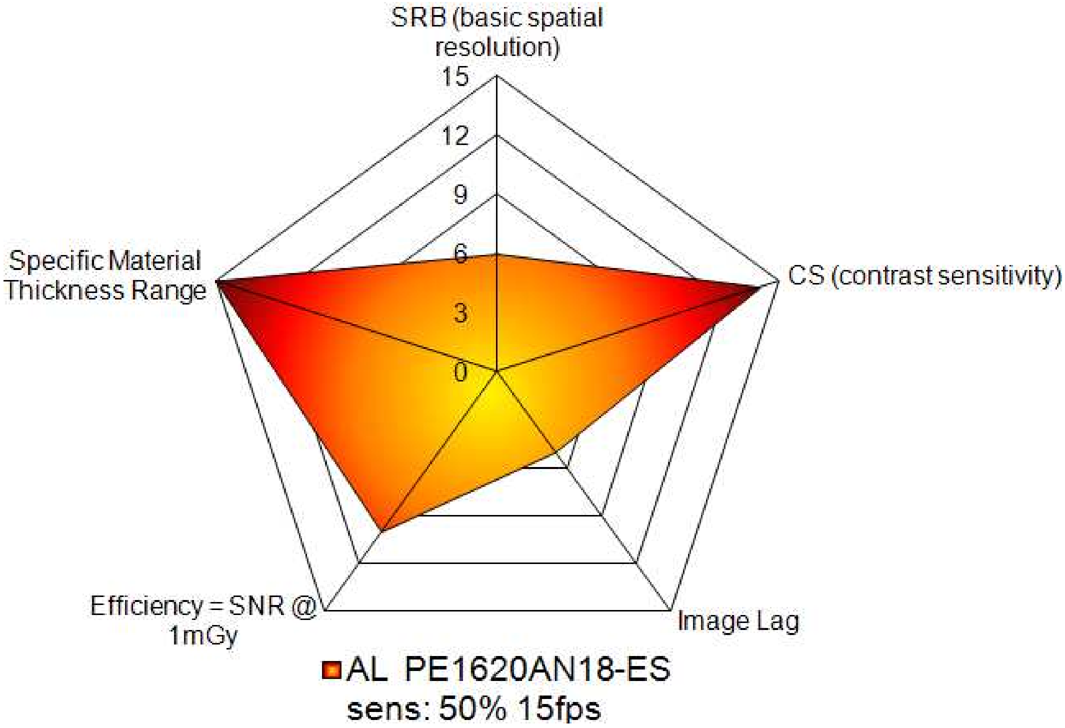


Figure 1: Typical spider-net diagram of a detector as known from the ASTM E 2597. The diagram shows the measurement results of a Perkin Elmer Detector for aluminum.

In general the image quality is proven using so-called image quality indicators (IQI) that are well-known from their specification, e.g. platinum duplex wires from EN 642-5 / ASTM E 2002 or plate hole indicators from ASTM E 1025 / E 1742. In [3, 6] was shown that a high *CNR* (Contrast to Noise Ratio) of an X-Ray image is the key feature of a reliable perception of IQIs or even for defects and other inhomogeneities. The *CNR* is proportional to the *SNR* (Signal to Noise Ratio) of the detector response and is derived by

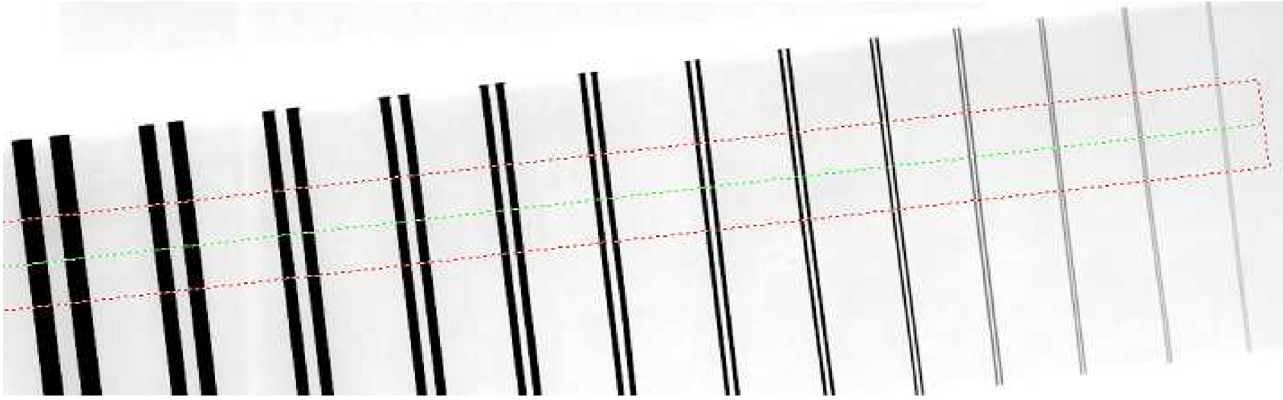
$$CNR = SNR \cdot \mu_{eff} \cdot \Delta w \qquad (1)$$

depending on the effective attenuation coefficient μ_{eff} and the wall thickness difference Δw.

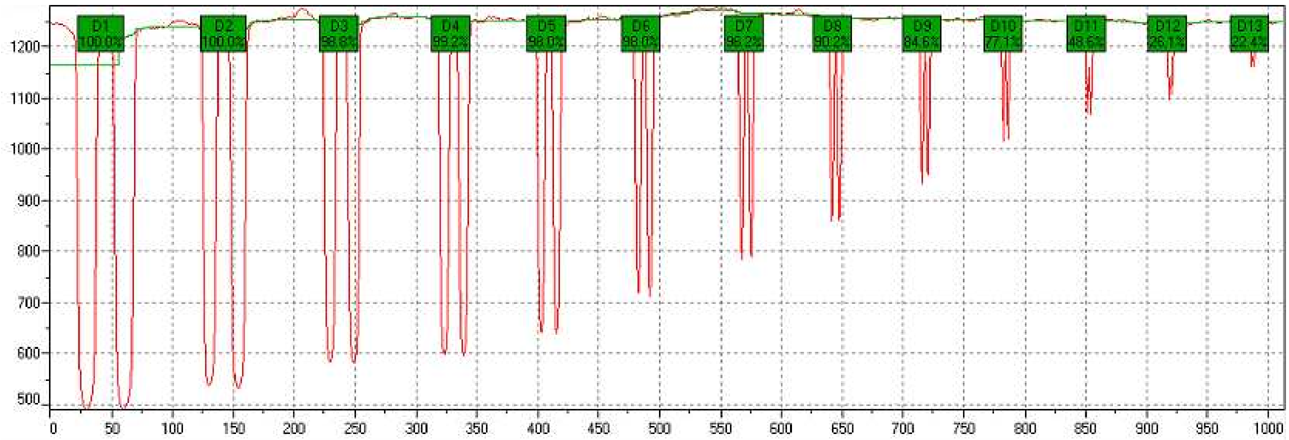
Therefore a high *SNR* is very important to reach a high image quality, i.e. the qualification of the X-Ray system should be proven regularly for example by using the mentioned IQIs above.

The system qualification using certain IQIs is automated by imaging software. The digital image is analyzed by software algorithms, i.e. the human inspector will not have to read the gray values and to do the calculations to compare the resulting values with the values specified in the current standards. Instead of this, the imaging software reports the results directly to the human inspector and visualizes the success of the system qualification.

In case of the automatic analysis of platinum duplex wires (EN 642-5 / ASTM E 2002) the contrast can be achieved fully automatically. Therefore a line profile is extracted from the X-Ray image perpendicularly to the duplex wires as shown in Figure 2.



(a)



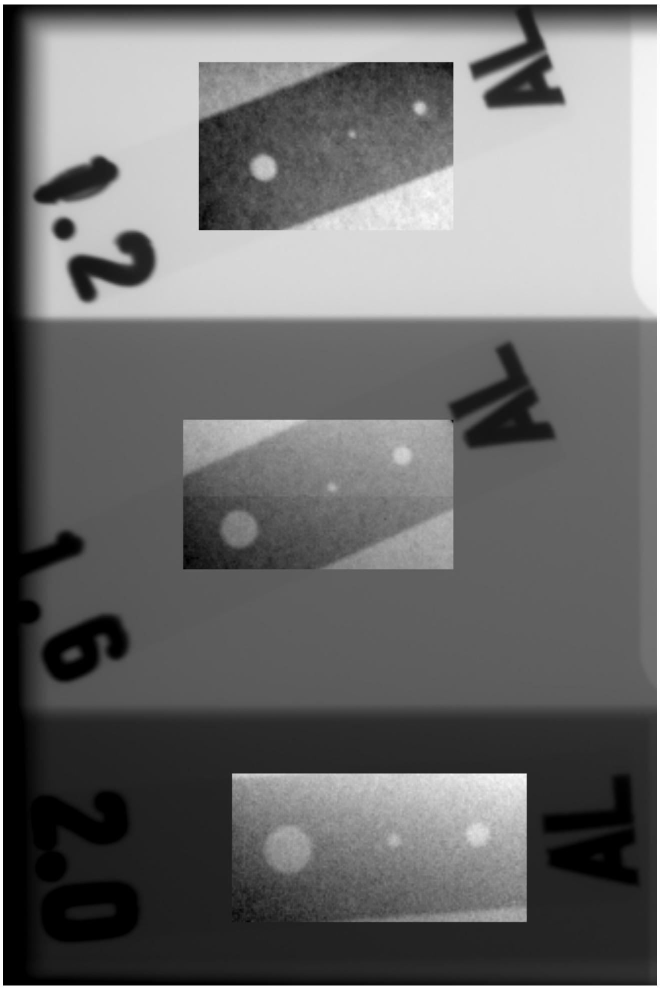
(b)

Figure 2: Line profile of platinum duplex wires (EN 642-5 / ASTM E 2002). The line profile (b) is extracted from the X-Ray image (a) perpendicularly to the duplex wires. The image processing software analyses the contrast resolution for each duplex wire in percent automatically.

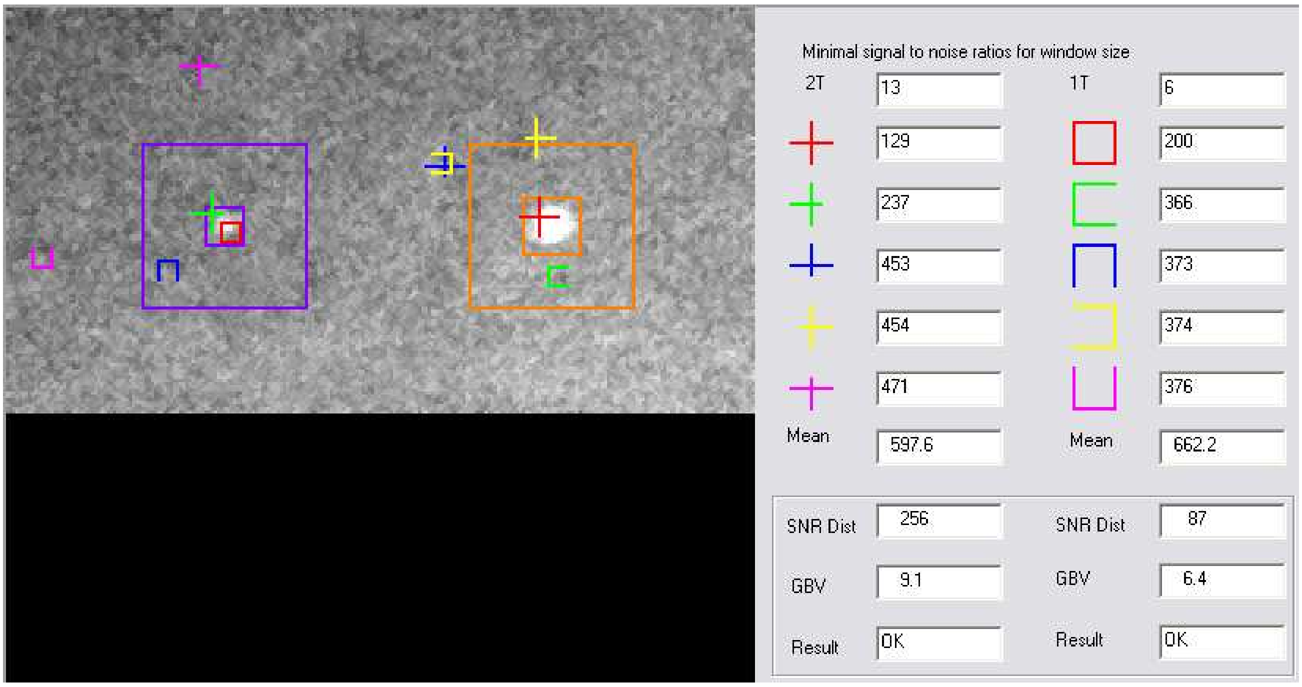
The contrast resolution of the platinum duplex wires has to be greater than 20% to fulfill the standard. In Figure 2 the human user can read out the results immediately, whereas the color is an additional indication up to which level the system is qualified.

The other method to prove the system qualification is a contrast sensitivity test following the standard ASTM E 1025 / E 1742. Here the main task is to measure the perceptibility of holes in a special plate.
The CNR is defined as quotient of the measured attenuation difference ΔI and noise σ or as the product of the relative contrast $\Delta I / I$ and SNR, i.e.

$$CNR = \frac{\Delta I}{\sigma} = \frac{\Delta I}{I} SNR \quad . \tag{2}$$

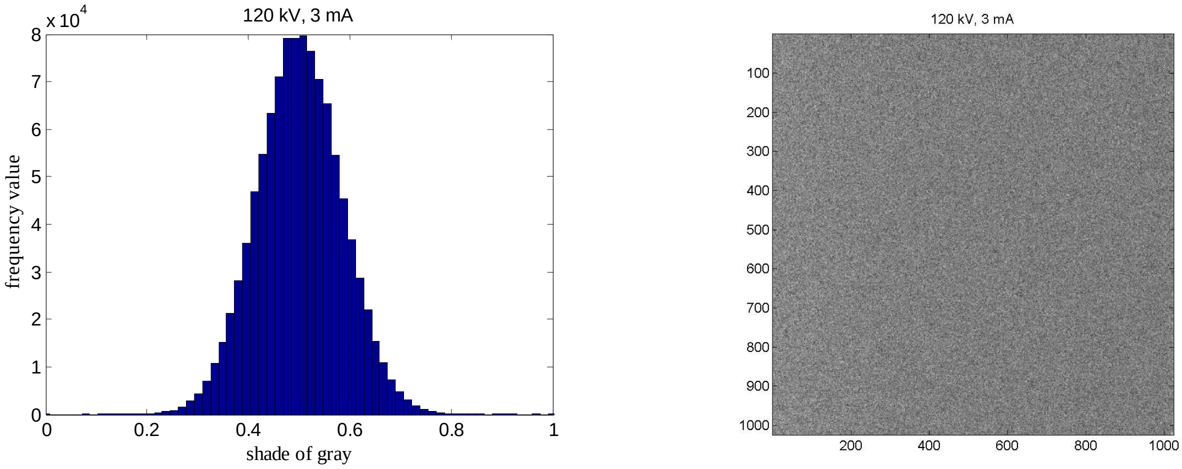


(a)



(b)

Figure 3: Automatic test of the perceptibility of holes in plates as defined by ASTM E 1025 / E 1742. (a) The so-called penetrameters are mounted on an aluminum step wedge. Here the holes have been made visible by enhancing the appropriate image regions. (b) The image processing software measures the SNR and rates the perceptibility of the so-called 2T or 1T holes automatically. The value of the field GBV is equivalent to the known CNR. In this example the result leads to OK for the 1T as well as for the 2T hole.



(a) **(b)**

Figure 4: Histogram. The histogram (a) visualizes the frequency distribution of the image (b).

From the X-Ray image the image-processing algorithm calculates the *CNR* directly as attenuation difference ΔI of the mean gray values inside and outside the holes divided by the local standard deviation σ outside the holes as noise. As shown in Figure 3 no further expert knowledge is needed by the human user for following the standard, because the results of the image qualification test is reported immediately and the perceptibility of the so-called 2T or 1T holes is measured and rated objectively.

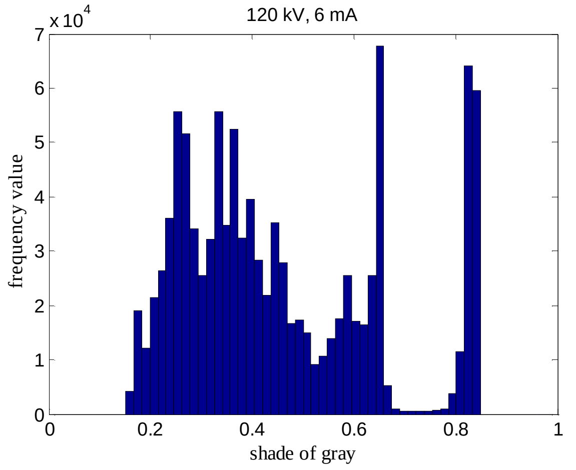
Automating Image Enhancement

From [6] and the previous section it is known that the higher CNR or SNR of the flat panel detectors is the key feature why this modern technique will replace traditional techniques like image intensifiers, film or CR in the next years. To be more precisely, a higher SNR means that the image contains lesser noise than before, i.e. structures and potential defects will not be hidden behind artifacts due to a high noise level of the traditional techniques.
A high-performance digital flat panel detector that provides spatial resolutions up to 200µm and 30Hz per full-frame, is equipped also with a contrast resolution of 14-16 bits, what is equal to a gray value range of 16384-65536 shades of gray. By comparison, actual image intensifiers will only provide a range of 4000 shades of gray (see [4]).
But a digital monitor still can display only 8 bits or 256 shades of gray.
Independently of the hardware the human eye can only differentiate about 60 shades of gray and even trained human inspectors will differentiate not more than approximately 80 shades of gray.

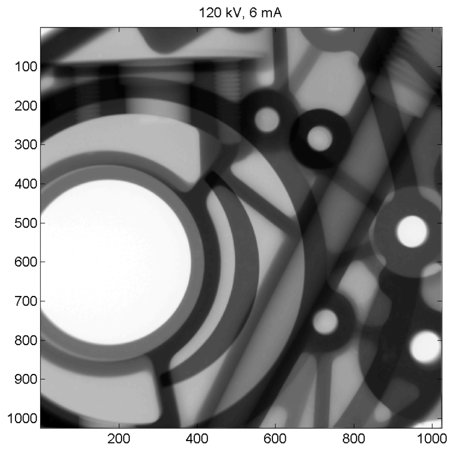
From this it becomes clear that a flat panel detector provides a much higher contrast resolution than a human inspector can ever realize it.
Therefore, for visual inspection certain image processing algorithms will be applied to optimize the visualization of the digital X-Ray images with respect to the needs of the human inspector's eyes.

In the times of the image intensifiers image enhancement was concentrated on reducing the noise of the X-Ray image. In contrast to medical applications, in industrial applications there is no need to care for a low X-Ray dose and the modern flat panels will provide images with a very high SNR.

This is the reason why the image enhancement of modern X-Ray inspection systems concentrates only on the optimal visualization of the information of the image, i.e. how to transform the information of the 16 bits to the 6 bits to overcome the limits of the underperforming perception of gray values of the humans.
A histogram is useful for extracting certain information out of an X-Ray image (see Figure 4).



(a)



(b)

Figure 5: Histogram of an X-Ray image. (a) The background information is coded in the high frequency values, i.e. represented by the peak on the right side of the histogram. (b) The dedicated X-Ray image.

The histogram visualizes the frequency distribution of the possible range of different shades of gray, i.e. the sum over all frequency values is equal to the number of pixels of the analyzed image.

In a histogram of a usual X-Ray image especially high frequency values are often an indicator for bigger homogeneous background regions of the same shade of gray.
If a test part does not hide the whole detector array, when it was penetrated, then the histogram of the resulting X-Ray image will show up a thin maximum somewhere in the upper range of shades of gray. Because of the missing material the background will become a bright, homogeneous region.
But the much more interesting image information of the test part is characterized by a wider maximum somewhere in the middle of the histogram (compare Figure 5).

An easy approach to optimize the visualization is to scale the whole value range depending on the contrast resolution of the detector to full resolution of the 8 bits or 256 shades of gray of the display. For each pixel *i* the displayed value $\hat{x}_i$ is derived from the pixel value x_i by

$$\hat{x}_i = \frac{x_i}{65535} \cdot 255 \tag{3}$$

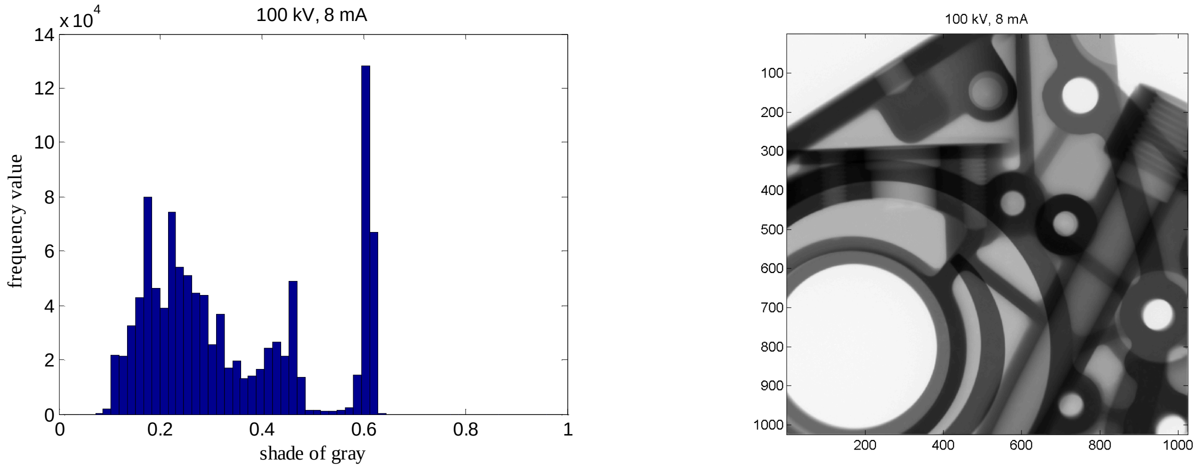
for a contrast resolution of 16 bits or

$$\hat{x}_i = \frac{x_i - x_{\min}}{x_{\max} - x_{\min}} \cdot 255 \tag{4}$$

if the image information is concentrated in a range between $x_{\min}$ and $x_{\max}$ somewhere in the middle of the possible range of shades of gray.
In the latter case the image processing algorithms will analyze the original X-Ray image with its high contrast resolution automatically to find the appropriate limits $x_{\min}$ and $x_{\max}$ of the interesting image information.
The following approach will determine the information content of the lower and upper range concerning the shades of gray. For this purpose the frequency *h(x)* of each shade of gray is accumulated beginning from the darkest to the brightest shade as long as the sum is lower than a given threshold *t*

$$\sum_x h(x) \le t\,. \tag{5}$$

This is also done backwards, i.e. accumulating the frequencies *h(x)* beginning with the brightest to the darkest shade.
Hereby not the full range will be scaled. The irrelevant information due to structural noise of the imaging system will be cut off. The resulting image will visualize the test part in good contrast.



(a) **(b)**

Figure 6: Bimodal histogram. (a) The peaky maximum on the right represents the homogenous background of the X-Ray image and the widespread maximum on the left the shades of gray belonging to the test part. (b) The dedicated X-Ray image.

In a histogram the maximum frequency h_{max} is called the mode. But as we have shown above still there could be several local maxima that can be described with the aid of the central moments especially the skewness, i.e. the asymmetry of the distribution, or the kurtosis, i.e. the 'peakedness' of the distribution as a measure if the local maximum is wide-spread or not.

Figure 6 depicts a bimodal histogram. The peaky maximum represents the homogenous background of the X-Ray image and the widespread maximum the shades of gray belonging to the test part, i.e. the interesting image information.

It is possible to find also these local maxima automatically using image-processing methods. But on the other side there could exist a test part that consists of different homogeneous regions with different material thickness. Then it would not be clear, how many local maxima will belong to the test part and how these maxima should be displayed, e.g. should the gray scaling toggle between the maxima or should all maxima be displayed together. In the latter case some regions might become very dark other very bright, so that the whole structure of the part could not be distinguished by the human inspector.

Therefore, we will describe another approach that uses the full contrast resolution of the modern flat panel detectors, but that compresses the information in such a way that all relevant information will be kept, when the image is displayed.

High Dynamic Radioscopy (HDR)

The High Dynamic Radioscopy (HDR) is a technique that has been developed in the last years to visualize the relevant information of X-Ray images with a high contrast resolution as known from the flat panel detectors (see [1, 4]). HDR benefits directly from the high performance of image processing hardware concerning image quality, the higher frame rate and the processing power using today's PCs.
The visualization of the image processing results is done directly on the live stream of the flat panel detectors without loosing a frame, i.e. actually a compression of the image information is done at a geometrical resolution of 1024 x 1024 pixels at a frame rate of 15 fps or at 512 x 512 pixels and a frame rate of 30 fps, but this will not be the end.

In Figure 7 the result of the live filtering is shown, i.e. the compression of the image information. The steady component of the image information has been removed, so that the histogram has become unimodal.

As we know from the previous section, such a frequency distribution can be scaled to the viewable range optimally. All the relevant information will become visible to the human eyes.

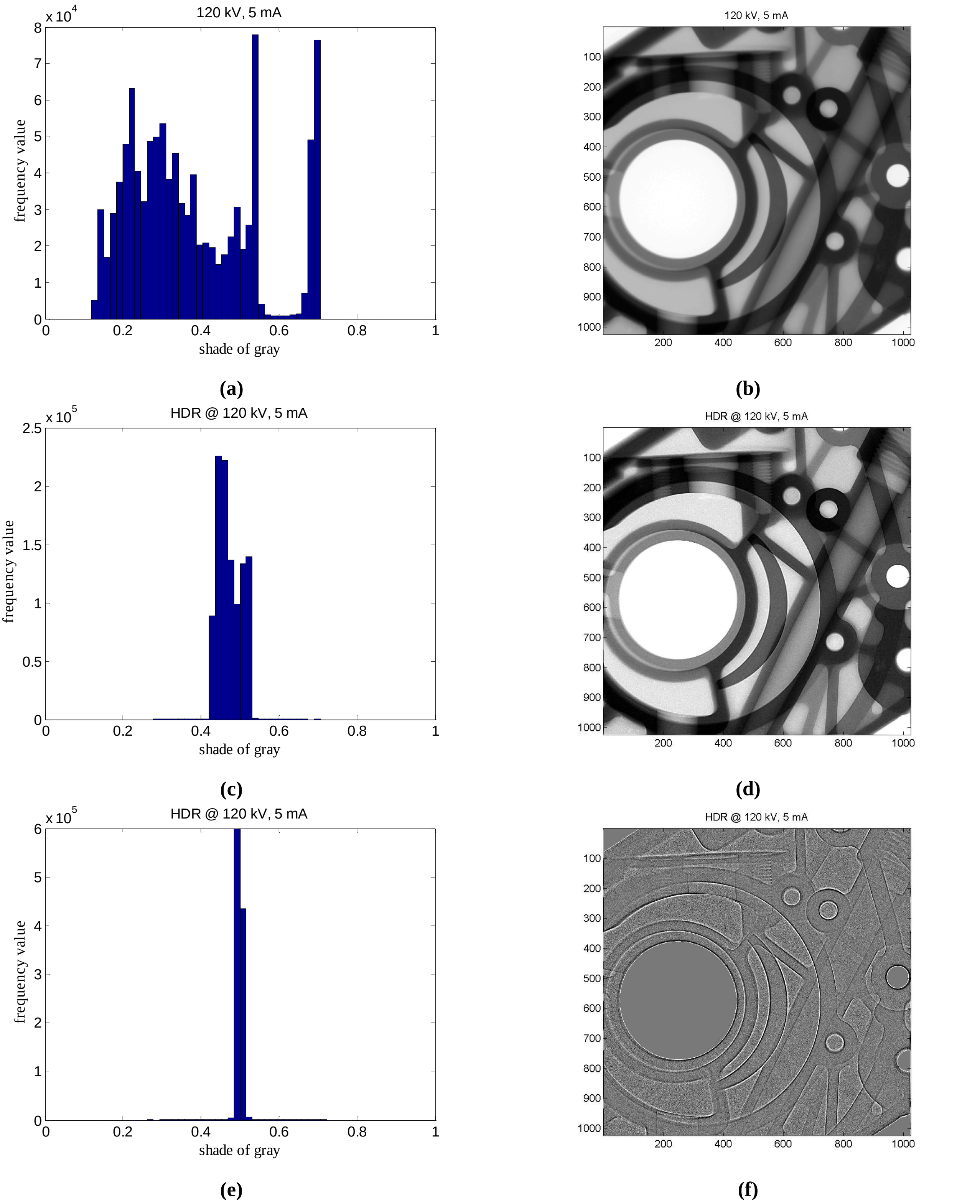


Figure 7: Histogram of HDR image. (a) The histogram of the image of the test part before HDR was applied. (b) The dedicated X-Ray image of (a). (c) The histogram representing the same test part as (a), but using the HDR live filtering to compress the image information. (d) The dedicated HDR image of (c). (e) Same as (c), but using a higher compression level for HDR. (f) The dedicated HDR image of (e).

Fully Automated Detector Calibration

In the previous section we mentioned the high image quality of flat panel detectors due to their superior SNR.
The SNR depends on the X-Ray dose directly. Therefore by increasing the exposure time, also the SNR will grow.
In contrast to techniques like film the exposure time of a flat panel detector could be increased endlessly, because just before the detector saturates the digital image could be stored in memory and the next time just before the detector saturates the next image is acquired and so on. All acquired images will be summed up and divided by the number of images. Computing the pixel-wise mean in such a way is called integrating the images.
The SNR value will increase with the square root of the member of averaged read out images.
Up to now the internal structure noise of the detector has been neglected. But the internal structure noise will limit the possible SNR, because every single pixel has its individual behavior concerning the received dose and compared to its neighbors.

By increasing the exposure time only the quantum noise will be reduced, but not the internal structure noise of the detector, which limits the SNR.

In [7] was shown that a calibration, e.g. a so-called multi-gain correction, will be necessary to reduce the internal structure noise. With the calibration the behavior of the detector pixel will be linearized in dependency on all detector pixel, so that in case of homogeneous dose distribution each pixel will correspondent to the same shade of gray.

Mainly, the multi-gain correction will reduce the internal structural noise to reach the maximal possible SNR, but also the integration cycles are reduced to reach a certain image quality, so that also the inspection speed can be increased.

Up to now a multi-gain correction means a very time-consuming manual work of experts. We distinguish between two kinds of calibration: calibration in-between air and calibration using material.

For calibration in-between air the following has to be done:

1. Set the X-Ray voltage using appropriate copper filters for beam hardening,
2. Adjusting the X-Ray current to reach several dose values and measure the shade of gray,
3. Use a linear approach to calculate the coefficients of the smoothing function.

For calibration using material (and appropriate copper filters) this receipt is applied:

1. Set X-Ray voltage and current to fix values,
2. Move material of different thickness to measure the shade of gray for several dose values,
3. Use a linear approach to calculate the coefficients of the smoothing function.

Especially, changing the calibration objects of the dedicated material is time-consuming. Also adjusting the appropriate X-Ray parameters has to be done by a certified expert, because it is very important to set the sample points of the multi-gain correction in a meaningful way to minimize the structural noise.

By using the feedback between imaging source and X-Ray these X-Ray parameters can be adjusted automatically. Therefore the image processing software will analyze the X-Ray images to calculate the needed parameters.
Exemplarily, we will describe the calibration in-between air. Assuming that there is no test part between X-Ray tube and detector and that the appropriate X-Ray voltage is set, the possible range of the X-Ray current is determined by the system.

To acquire the offset image X-Ray has to be switched off. The live image stream will be analyzed sequentially to make sure that there are no artifacts due to the detector lag in the offset image.

After acquiring the offset image and activating the offset correction the detector response will be measured for a certain X-Ray test current. Due to the linear relation between X-Ray current and the measured intensity by the detector the X-Ray current for a certain shade of gray may be estimated. For the X-Ray current I the dedicated shade of gray x is

$$I = g_{const} \cdot x \tag{6}$$

whereas g_{const} is a constant gradient. Thus, for a fix X-Ray voltage the possible range Int_{pos} of the X-Ray current $[I_{\min}..I_{\max}]$ results to the theoretical possible range of shades of gray by

$$Int_{pos} = \left[\frac{I_{\min}}{g_{const}} .. \frac{I_{\max}}{g_{const}} \right]. \tag{7}$$

For example for a contrast resolution of 16 bits of the flat panel detector the maximal range $Int_{\max}$ of shades of gray is given by

$$Int_{\max} = [0..65535]. \tag{8}$$

From (7) and (8) the estimated usable range Int_{use} of shades of gray is

$$Int_{use} = Int_{pos} \cap Int_{\max}. \tag{9}$$

To avoid using the detector in saturation the limits of the X-Ray current are calculated from (9) by

$$\tilde{I}_{\min} = g_{const} \cdot \min(Int_{use}), \tag{10}$$

$$\tilde{I}_{\max} = g_{const} \cdot \max(Int_{use}). \tag{11}$$

To estimate the expected shades of gray that correspondent to the interpolation points of the multi-gain correction the attenuation law of mono-energetic and collimated radiation is applied

$$x(w, E) = x_{\max} \cdot e^{-\mu(E)w} \tag{12}$$

with the attenuation coefficient μ depending on the kind of material and the energy E and the material thickness w. The maximal material thickness that can be penetrated by the given energy E is divided into equidistant steps in accordance to the interpolation points of the multi-gain correction. Applying (6) and (12) the expected values of the X-Ray current of the dedicated shades of gray are estimated. The estimated X-Ray currents are adjusted automatically and the dedicated so-called gain images are acquired.

Additionally, the bad-pixels of the currently used detector will be extracted by the procedures described in the standard ASTM E 2597 in parallel to acquiring the offset and gain images.

The described automatic calibration procedure above can be initiated by the system itself or will be reduced to just one click by the human user to start the procedure.

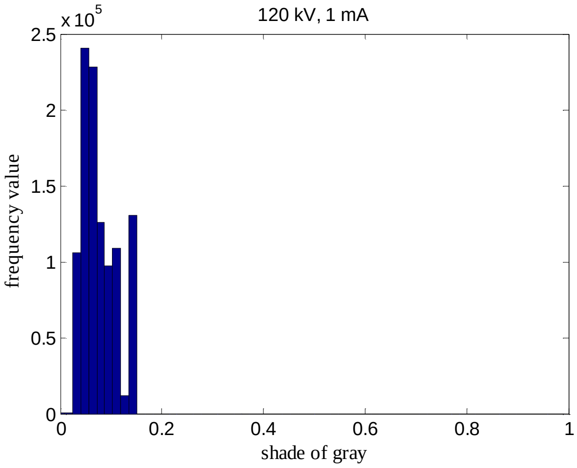
Automating The Adjustment Of X-Ray Parameters

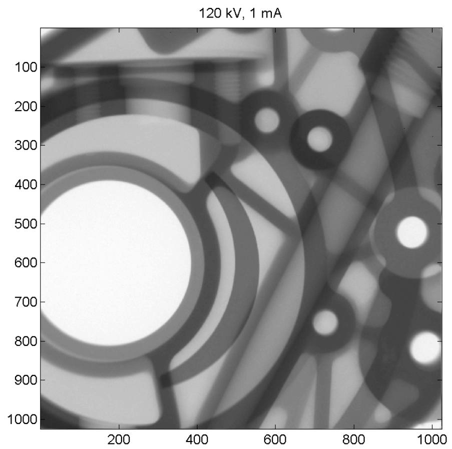
In the previous section we have shown, how to calculate and to adjust the X-Ray parameters automatically to perform a calibration necessary for multi-gain correction fully automatically. The information from the X-Ray image was used as feedback to control the X-Ray source. An overdose control is already known from image intensifier systems. But by using intelligent software algorithms more complex control loops are applicable.

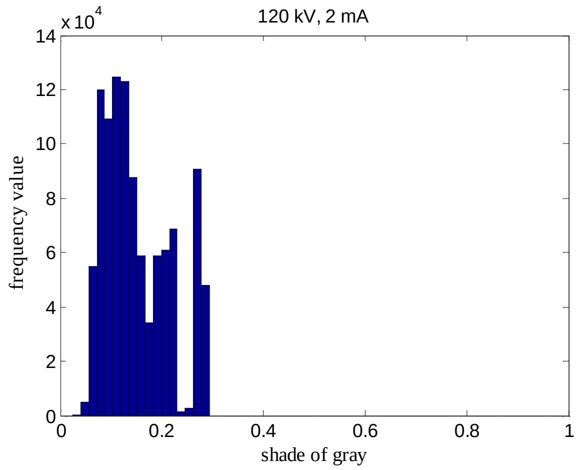
From the section Automating Image Enhancement the histogram is known as visualization of the image information, especially in the context of analyzing the image quality.

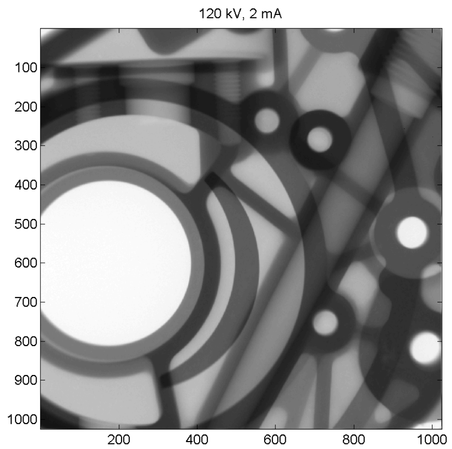
Therefore a modern visual system is also able to do the adjustment of X-Ray parameters for visual inspection automatically.

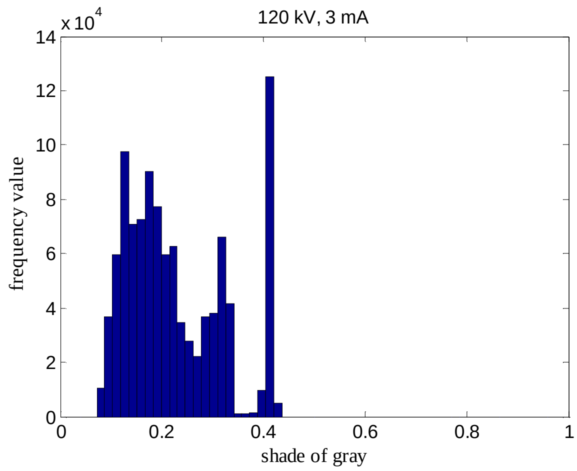
The human inspector will only put in and position the actual test part. After this the system will start to increase the X-Ray voltage, while the X-Ray current follows maximally (iso-watt operation mode). The voltage will be increased until the wide local maximum of the test part fills out the maximal possible range of the histogram concerning the contrast resolution of the detector.

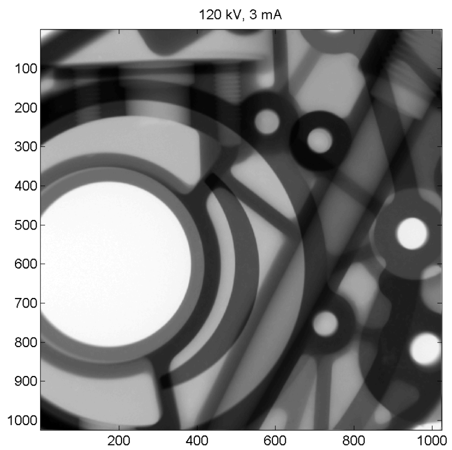




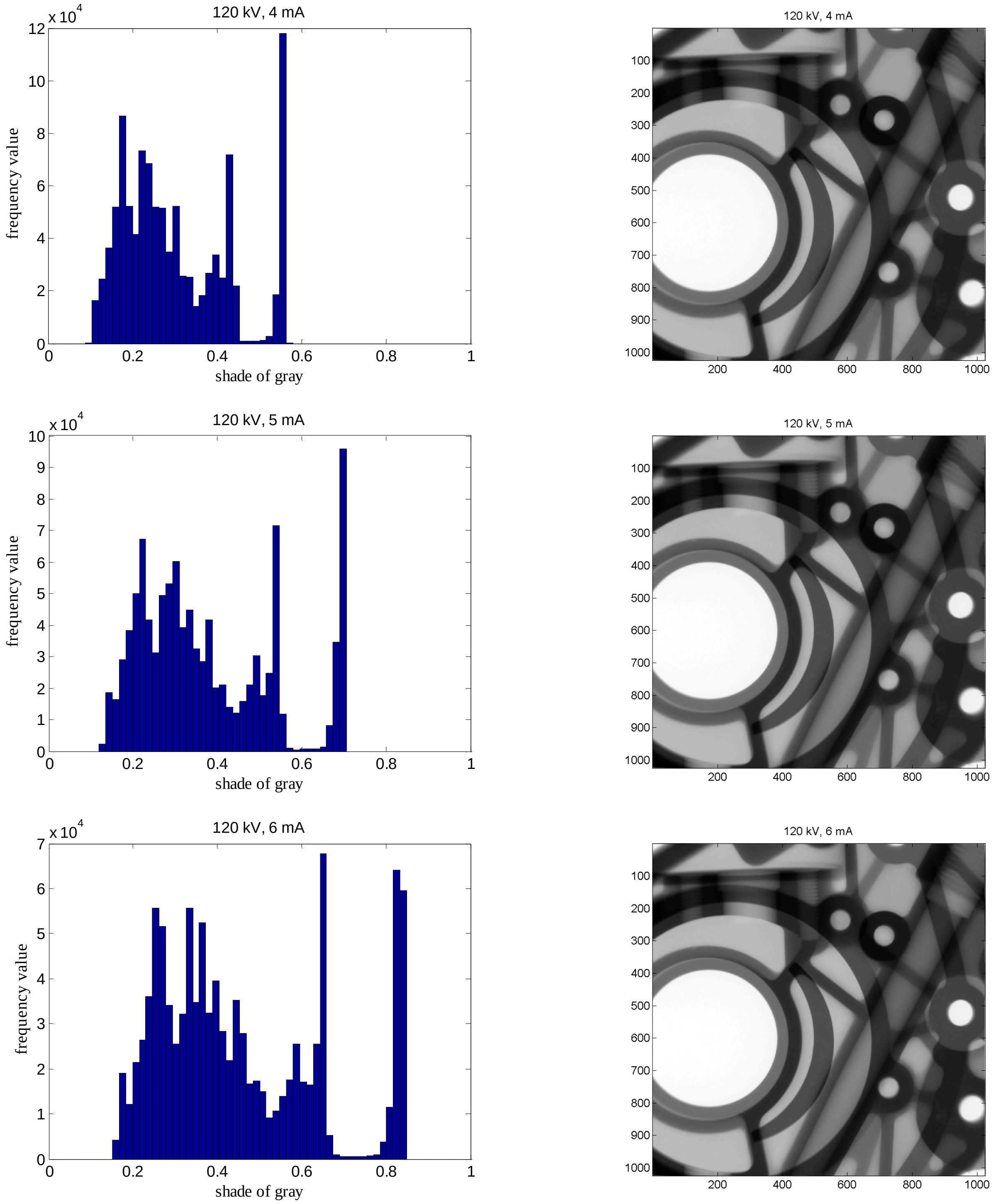








(continued on next side..)



(a) **(b)**

Figure 8: Sequence of histograms during automatic adjustment of X-Ray parameters. (a) Histogram. (b) Dedicated X-Ray image of (a) on the left side.

By using this automatism the detector will not become saturated, what also will prevent the detector being affected from aging effects too soon.
Moreover by applying maximal dose to the detector, the SNR will be optimized in correspondence to the chosen frame rate, the material and the penetrated material's thickness.

Exemplarily, Figure 8 visualizes the sequence of histograms, when starting the adjustment of X-Ray parameters until the optimal dose has been found. In this case another strategy has been used. The X-Ray voltage has been kept stable and the X-Ray current has been adjusted iteratively.

Automating Background Segmentation

Due to the feedback between X-Ray image analysis and the X-Ray source and manipulator system there are possibilities to segment the regions of an image: regions, which belong to the test part, and regions, which belong to the background, i.e. the test part does not hide the full area of the detector.

A trivial approach would be to illuminate the detector with the appropriate dose one time without and one time with the test part in-between X-Ray source and detector. The region in shape of the projected test part is obtained from the difference of both images.

Another approach will segment the background by moving the manipulator a little bit. In the live series of X-Ray images the movement can be detected by standard image processing algorithms [8].

An approach using the feedback to the X-Ray source will take advantage of the attenuation law of mono-energetic and collimated radiation (12). The attenuation coefficient μ is dependent on the material thickness and the energy E. Anyway, the effect of the attenuation law is only visible on the region in shape of the projected test part.
On the other hand there is a linear relation between X-Ray current and the resulting shade of gray on the detector (6), in case that there is only air in-between X-Ray source and detector.

By increasing the X-Ray current in a linear way the pixels of the acquired images of the detector will react in a two different ways to the changes of dose. The shades of gray of pixels belonging to the background will increase linearly as known from the calibration procedure (see above), whereas the shades of gray for pixels belonging to the projection of the part will follow the attenuation law additionally. Thus the background will be separated from the region of the test part. Figure 9 visualizes the different behaviors of regions belonging either to the background or to the test part. The parts of the line profiles that lie in between the interval ΔX will be the classified as background.

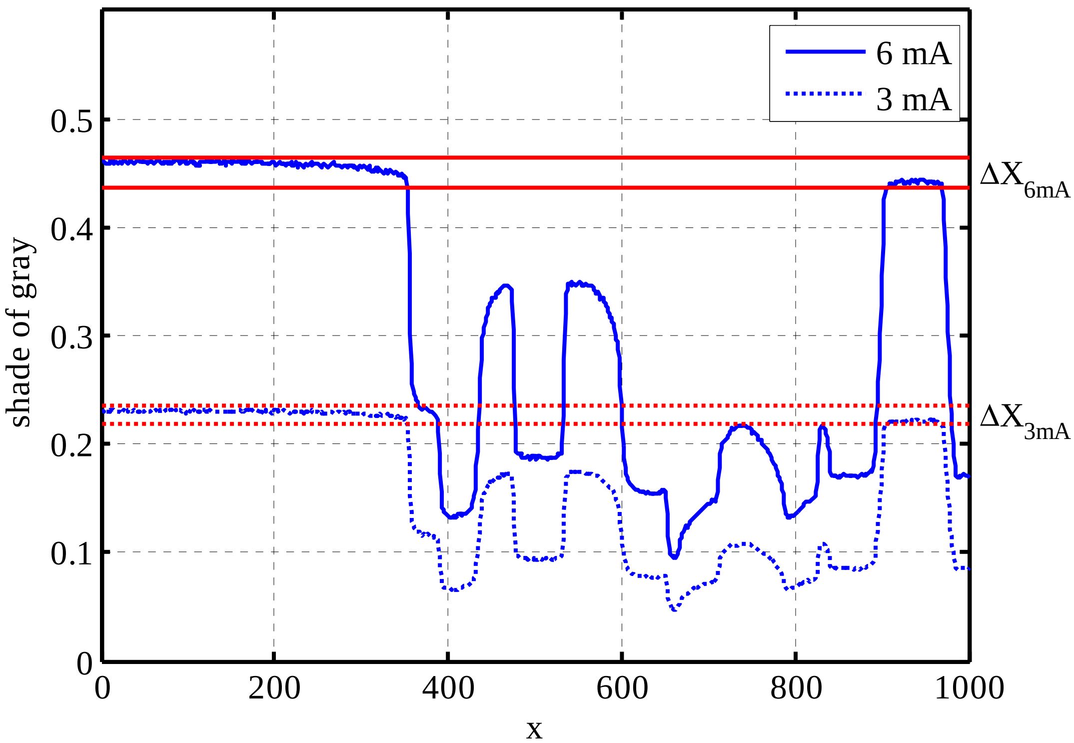


Figure 9: Segmenting the regions of the background of a test part. As an example the same test part as known from Figure 8 has been used. The two line profiles represent two X-Ray images at the identical viewing position of the test part. The first image has been acquired at an X-Ray current of 3 mA and the second at 6 mA, both times using the same X-Ray voltage. By calculating the dedicated interval ΔX for the both line profiles the background can be segmented automatically.

Conclusion

In this article we have studied several use cases visualizing the potential of automating X-Ray inspection systems concerning mainly visual systems, but also one use case, which is applicable to the well known ADR systems [9].

The automation of X-Ray inspection systems has become possible due to intelligent image processing algorithms in combination with the feedback between imaging source, X-Ray source and the manipulator.

New digital image processing hard- and software will replace the analog techniques step by step, e.g. techniques like film or CR [6]. But even the image intensifiers will be replaced by high-performance digital flat panel detectors, which provide spatial resolutions up to 200µm and 30Hz per full-frame. These detectors are characterized by their high image quality, e.g. a superior SNR and a high contrast resolution of 16 bits. Today's flat panels detectors are running on a geometrical resolution of 1024 x 1024 pixels at a frame rate of 15 fps or at 512 x 512 pixels and a frame rate of 30 fps.

The high image quality is the prerequisite for all robust and reliable image analysis algorithms. Therefore the image quality has to be proven periodically.
In this article we have shown, how the image quality tests in compliance to the standards EN 642-5 / ASTM E 2002 (platinum duplex wires) or ASTM E 1025 / E 1742 (plate hole indicators) have been automated and how the results are reported to the human inspector automatically [3, 6]. These essential image quality tests are done in minutes in an objective and reproducible manner.

The image enhancement of modern visual systems only has to concentrate on the optimal visualization of the image information, because of the mentioned high image quality of the flat panel detectors. The quantum noise is no longer the limiting factor [6].

By introducing the meaning of histograms for image analysis we have shown, how the image information of an image with a contrast resolution of 16 bits can be made visible to the human eye that only provides a contrast resolution of approximately 6 bits.

Further we have shown the limits of visualizing only parts of the possible range of different shades of gray. To overcome these limitations we have shown, how to compress the image information represented by a unimodal histogram shape by HDR [1, 4]. This way the image information can be scaled and visualized to the human eye's perceptibility easily.

HDR provides this compressed image information in real-time, i.e. like the default gray scaling is done directly on the image live stream, also the filtering for HDR is done on the live stream directly. As mentioned above, this means for 1024 x 1024 pixels a frame rate of 15 fps or for 512 x 512 pixels a frame rate of 30 fps.

The detector calibration is very important due to the fact that for flat panel detectors the only limiting factor is the structure noise in accordance to maximizing the SNR. We have shown, how a calibration, a so-called multi-gain correction[7], can run fully automatically.
In case of an in-between air calibration the feedback between imaging source and X-Ray source has to be used. Additionally, in case of a calibration with material the feedback to the manipulator will be needed.

We have described the automatic internal calibration procedure in case of the in-between air calibration in detail. Such a calibration can be initiated by the system itself or by the just one click of the human user.
The calibration will take a few minutes depending on the actual frame rate and resolution of the detector as well as on the needed image quality for certain applications.

As add-on to the prior mentioned automated procedures we have shown, how analyzing the histogram could do an optimal adjustment of X-Ray parameters for visual inspection.
The human inspector only has to put in and to position the test part. The optimal X-Ray dose will be adapted on the fly automatically.
Another use case that is also suitable for ADR systems [9] is the automatic background segmentation by taking advantage of the feedback between imaging and X-Ray source. This segmentation is also designed for execution on the fly, i.e. while increasing the X-Ray power automatically.

All the use cases demonstrate the advantage of automating X-Ray inspection systems. The results are always independent on the human condition or the individual skills. The results are objective and reproducible. Most of the described methods are running in real-time or in a few minutes significantly faster than before, because there is no interaction by the human inspector needed anymore.

The intelligent image processing algorithms take over the complex and time-consuming adjustments of the hard- and software, i.e. no further expert knowledge has to be applied.
In the future X-Ray inspection systems will do all of the daily needed systematic adjustments automatically. The goal is that the human inspector should only use the system and not have to do the setup every day again. Of course, there will be still the possibility to adapt the system depending on the individual expert knowledge, but this has not to be done every day again.

Therefore the human inspector can concentrate mainly on NDT.

References

[1] K. Bavendiek, U. Heike, “HDR Hoch Dynamik Radioskopie”, DGZfP Jahrestagung 2009, Münster, Germany.
[2] K. Bavendiek, “Film, CR, and Flat Panel Detectors for BAM 5 Reference Weld”, ASTM Conference, Reno (NV), June 2005.
[3] K. Bavendiek, U. Zscherpel, U. Ewert: “Digital Detector Arrays (DDA) for X-Ray Micro Imaging”, IEEE Workshop on X-Ray Micro Imaging of Materials, Devices, and Organisms, October 2008, Dresden, Germany.
[4] K. Bavendiek, “Erweiterung der visuellen Röntgenprüfung durch effizientere digitale Technologien: Mit HDR schneller und sicherer zum Ziel”, MP Materials Testing, Volume 52, 2010, Carl Hanser Verlag, München, Germany, ISSN: 0025-5300.
[5] K. Bavendiek, U. Heike, F. Herold, “Automated Defect Recognition in Industrial Applications”, International Workshop on Imaging NDE, April 2007, Kalpakkam, India.
[6] U. Ewert, K. Bavendiek, J. Robbins, U. Zscherpel, C. Bueno, T. Gordon, D. Mishra, “New Compensation Principles For Enhanced Image Quality In Industrial Radiology With Digital Detector Arrays”, ASNT Fall Conference, Columbus (Ohio), October 2009.
[7] U. Ewert, U. Zscherpel, K. Bavendiek, “Strategies for Film Replacement in Radiography”, IV Pan-American Conference for Non-Destructive Testing, October 2007, Buenos Aires, Argentina.
[8] R. Gonzalez, R. Woods, “Digital Image Processing”, 2nd edition, Prentice Hall, Pearson Education, Upper Saddle River, New Jersey, 2002, ISBN: 0-201-18075-8.
[9] F. Herold, S. Frantz, K. Bavendiek, R. Grigat, “Building Blocks of Third-Generation Automatic Defect Recognition System”, 9th European Conference on NDT, September 2006, Berlin, Germany.
[10] P. Soille, “Morphological Image Analysis”, 2nd edition, Springer, Berlin, Germany, 2003, ISBN: 3-540-42988-3.