Digital Radiography: Description and User's Guide

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Abstract
The presented document arises from the work of the group "Digital Radiography and sensors" of COFREND. It is a collective work of synthesis aimed to analyze the quality parameters of digital images influencing the answer and the diagnosis brought to a given industrial problem. Five families of digital sensors have been studied : 1. Image Intensifier coupled with CCD devices – 2. scintillators coupled with a CCD device- 3. Flat Panels with indirect conversion – 4. Flat Panels with direct electric conversion – 5. Photostimulable Storage Phosphor Screens). In particular, concerning a complete imaging chain, it deals with the notions of magnification, blur (unsharpness) (geometrical, kinetic or internal to the very sensor), noises, scattered radiation, spatial resolution, which is different from the one of analog detectors such as films, Contrast to Noise Ratio (CNR), sensitivity using IQIs, dynamic range, detection quantum efficiency, persistence and temporal resolution. This document is not a standard; it must be understood as a user's guide, and it approaches some essentials corrections to bring to a sensor in order to optimize his efficiency without losing information during the pre-processing phase in the radiographic acquisition. It also introduces some image processing tools commonly used. It can be used as a source document to the future elaboration of a standardisation document. It augurs not at all of the choice of a digital sensor with regard to the traditional radiographic film, but gives bases of reflection to a radio user for a sensible transfer from the classic radiography to the digital radiography.
Keywords: Digital Radiography, digitalization, numeric sensors, image quality parameters, corrections of the sensor, image treatment.

1 Introduction

Seeing and measuring inside substance thanks to radiography allows to obtain basic knowledge in materials' physics and also constitutes an privileged mean for the control of the processes and the quality controls (dimensional controls, health material…). That is why we tried to develop on one hand fast, intense and punctual, in other words brilliant X-ray sources, and on the other hand image sensors both spatially resolved, and sensitive (perceptible), of weak threshold, and fast also.

Digital radiography differs from conventional radiography using film by the use of a detector restoring a digitized image without resorting to processes of chemical revelation. The obtained image contains information relative to the easing of a beam from an X-rays source or a gamma source and this in every point or pixel of the image. The technologies of detectors and digital sensors offer solutions for photonic radiations of energies scaled between tens of keV and several MeV.

Digital radiography presents numerous advantages: a big dynamics bounded to an mostly linear response; an interactive parameter setting the examinations devices; a quasi-immediate availability of the image; operations of post-treatment on the images in order to improve their quality; the availability and the sharing of the images on local or distant stations.

Today, the greater needs in flexibility and "real time", as well for the acquisition of the images as for the communications, the sharing of information, the processing and the computing exploitation of the big data bases of images, as well as the more and more frequent exploitation of the temporal dimension (movies-radiography) make the use of one of these new systems of digital radiography almost indispensable. The emergence of these technologies was allowed by progress of electronics and computing science and needs in instrumentation evolved at the same time as the increase of the performances of the computing simulation tools.

The either optoelectronics or semiconductor new sensors achieve performances which can on certain points exceed those of the film systems:

- high power of ruling allowing a high threshold of detection,
- noise only limited by the statistics of detected photons X,
- dynamics above 1000,
- linearity on all the range of signal,
- speed of evacuation of the data
- frame rate…

The first attempts to go further than the performances of films cells began with the use of image intensifiers (vacuum tubes or micro-channels). A photocathode, alkaline or metal, realized the electron / photon conversion. Certain "medical" tubes had a sparkling screen in the front of the photocathode (tri-alkaline). The electronic tube or the micro-channels amplified the secondary image transported by the emitted photo-electrons, with an electronic gain of about 103. Finally, the image with amplified photo-electrons was focused on a fluorescent screen to be converted in a visible image recorded on a film or a television tube.

This time, new and even more successful technologies have been developed (mainly based on scintillators or semiconductors). Figure 1 illustrates some existing geometries of detectors usually employed.

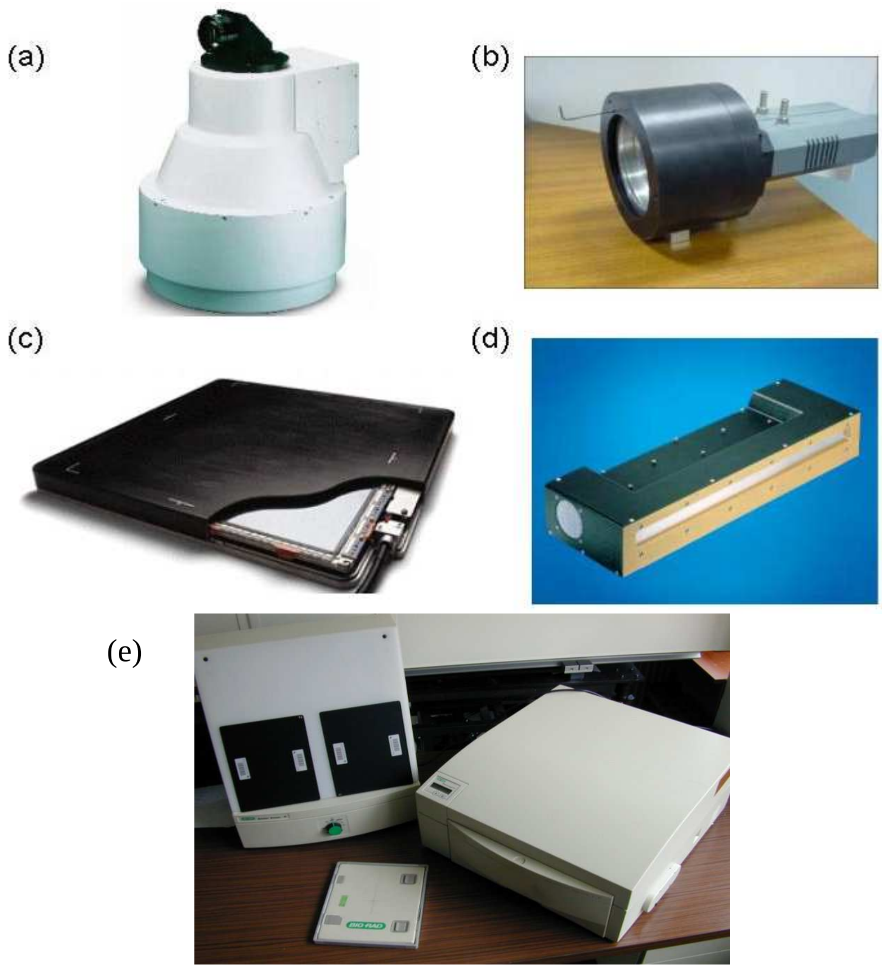

Figure 1 (a) : Image Intensifier (b) : Scintillator with a CCD device
(c) : Flat Panel (d) : linear detector (e) Phosphor plate + reading system

These detectors are extremely successful but the experimental conditions must be carefully mastered in case of quantitative measures. This is the object of the following chapters.

2 Application fields

Digital radiography covers completely the field of conventional industrial radiography by adding the “real-time” applications (treatment and interpretation of the images obtained in live by an operator) and the "fast" imaging (acquisition of images of fast phenomena with treatment and interpretation of the images in slow motion).

This document deals with the imaging station, the various sensors and the processing it is possible to apply to the images. The concerned digital sensors are: the image intensifier with resumption of integrated or deported images, the scintillators opticaly coupled with a CCD or CMOS component, flat panels (or flat screens) and the linear pins (or linear detector array) in direct conversion (semiconductor) or indirect (scintillator), phosphor plate. The measure and the follow-up of the performances associated with these sensors will be studied.

This document excludes the digitalization of films, object of the standard IN 14096-1 and 14096-2.

It concerns readers already possessing basic knowledge in radiography. The principles of radiography will not be resumed.

3 Standardisation references

This document contains elements of other publications with dated or undated reference. These standard references are quoted in the appropriate places in the text and the publications are enumerated below.

EN 444, Principes généraux de l’examen radiographique à l’aide de rayons X et gamma des matériaux métalliques. (General principles of the radiographic examination by means of X-rays and gamma of the metal materials).

EN 462 - partie 5, qualité d’image des radiogrammes : indicateurs de qualité d’image (duplex à fils), détermination de l’indice de flou de l’image. (image quality of radiograms: image quality indicators (wire-duplex), determination of the indication of blurring of the image).

EN 13068-1, Contrôle par radioscopie : mesure quantitative des caractéristiques d’image (Control by radioscopy: quantitative measure of the characteristics of image).

EN 13068-2, Contrôle par radioscopie : contrôle de la stabilité à long terme des systèmes d’imagerie (Control by radioscopy: control of the long-term stability of the imaging systems).
PrEN 13068-3, Contrôle par radioscopie : principes généraux du contrôle par radioscopie des matériaux métalliques par rayonnement X et rayonnement gamma (Controls by radioscopy: general principles of the radioscopy control of metallic materials by X-Rays and Gamma-Rays).

EN 14096-1, Qualification des systèmes de numérisation des films radiographiques : définitions, mesures quantitatives des paramètres de qualité d'image, film de référence normalisé et contrôle qualitatif (Qualification of the radiographic films digitalization systems : definitions, quantitative measures of the quality parameters of image, standardized reference film and qualitative control).

EN 14096-2, Qualification des systèmes de numérisation des films radiographiques : exigences minimales. (Qualification of the radiographic films digitalization systems : minimal requirements)

EN 14784-1, Radiographie industrielle numérisée avec des plaques – images au phosphore : classification des systèmes (Industrial Radiography digitized with phosphor plates : classification of the systems).

EN 14784-2, Radiographie industrielle numérisée avec des plaques – images au phosphore : principes généraux de l'essai radioscopique, à l'aide de rayons X et gamma, des matériaux métalliques (Industrial Radiography digitized with phosphor plates : general purpose of the radioscopic essay by means of X-rays and Gamma-rays, of metallic materials)

E2339-04 Standard Practice for Digital Imaging and Communication in Non Destructive Evaluation

4 Symbols and abbreviations

APS : Active Pixel Sensor (CMOS technology)
CCD : Charge Coupled Device
CNR : Contrast to Noise Ratio
CR : Computed Radiography
DR : Digital Radiography
DQE : Detection Quantum Efficiency
FPD : Flat Panel Detector
FPI : Flat Panel Imager
IQI : Image Quality Indicator
LDA : Linear Detector Array
MCP : Multi Channel Plate
MTF : Modulation Transfert Function
PSP : Photostimulable Storage Phosphor
ROI : Region Of Interest
RX : X-Rays
SNR : Signal to Noise Ratio
TDI : Time Delay Integration
TFT : Thin Field Transistor
XRII : X-Ray Image Intensifier

5 Global description of a digital imaging device

The digital imaging device includes the radiation source, the object carrying device, the detector and the environment. The intercompatibility between these elements is widely going to influence the performances of the radiography device.

5.1 Radiation source

Industrial Radiography with industrial custom uses four types of radiation sources: (1) radiogenic tubes, (2) linear accelerators, (3) isotopes (gamma radiation) and (4) synchrotrons. The two first produce a wide energy spectrum (polychromatic sources). The emission of photons corresponds to the braking of electrons in metal targets: we speak about braking radiation. The third type uses radioactive sources, whose spectrum includes only some emission ray energy: monochromatic with a single ray for the cesium 137 to 0,66 MeV, two very close rays for the cobalt 60 (1,17 and 1,33 MeV), and polychromatic for the iridium 192 with 4 main rays (between 0,20 and 0,61 MeV). The fourth type uses turning electrons in a ring, whose trajectory is disrupted by magnets. This rough disturbance is at the origin of an intense production of photons X emitted in a very slight solid angle, offering the possibility of a monochromatic radiation.

Most of the existing radiography devices appeal to the electric sources of braking radiation. Their main advantage with regard to an isotopic source is that the generated flux of photons is much higher, which allows reduced time of scanning. Their main disadvantage is the effect of beam hardening associated with the polychromatic flux which results from the preferential absorption, during the crossing of the object, from photons of lower energy. The industrial devices conceived for a moderate penetration use radiogenic tubes generally between 100 kV and 450 kV. The systems dedicated to examine very voluminous or very dense objects use a braking radiation with high energy produced by linear accelerators. These sources have a high flux and a good penetration, but they also have a wide continuous spectrum which is associated with the effect of beam hardening. Isotopic sources are interesting for certain applications. With regard to radiogenic sources, isotopes do not raise the problems associated with the beam hardening, and present other advantages, because they do not require either source of electric power supply, or system of cooling and because they deliver an intrinsically more stable intensity. The intensity delivered by available isotopic sources is however limited by their weak specific activity (photons / second by gram of material). The intensity has an incidence on the signal-to-noise ratio and, more important still, the particular activity determines the dimension of the emissive focus of the source and thus the spatial resolution. These two factors tend to limit the industrial application of isotopic devices. Nevertheless, they can be used in certain applications where the resolution or the scanning time are not critical.

A filter can be used to minimize the spectrum hardening in the case of polychromatic beams. The choice of the material and its thickness depends on the application.

The X-rays source (according to its type) can emit continuously or by pulsation. For the functioning regulations in pulsed mode, the parameters are the duration of an impulse and the temporal frequency of the impulses. The pulsed mode allows to minimize the warming of the anode (the target) by stretching out in time the calorific contribution of a shooting but by keeping the wished dose.

Placed nearest the focus, a collimator allows limitation of the beam according to the useful field of the detector and the geometry of the device. This collimator will also limit the backscattering radiation generated within the object and in the room itself. It defines a solid angle in a given direction.

5.2 Object

A precise evaluation of the characteristics of the object, as well as indications to be detected, before controls, is essential. The various criteria are:

- Volume, size of the object, dimensions: for the large dimensions objects requiring a very vast field, it is possible to realize several X-rays radiographs, then to assemble them to create a "mosaic" of images. The (sometimes voluminous) size of certain image formats influences directly the number of images which it is reasonably possible to assemble.
- Materials (Density and atomic numbers): some digital detectors are conceived for a range of given energy. Materials of high density require X high energy photons, sometimes out of the native range of the sensor.
- Nature of the indications to be detected and orientation with regard to the object and to the beam: the choice of the angle has to take into account the decrease of enfeeblement provoked by the nature and the geometry of the indication.
- Exploration zones: according to the wished expertise, some set “Source - Object – Sensor” are not geometrically possible. The digital detectors are stiff, only phosphor plates present certain flexibility. The speed of acquisition of the numeric images allows the reproduction of the shootings, and thus, their optimization.

5.3 Mechanics

Mechanics, which allows aligning and determining the place of the components, is an essential element in a digital imaging device.

It must allow scanning of the object partially or completely. The number of scanning axes depends on the type of detector and on the controlled object. For linear detectors, one or several orthogonal movements in the detector have to present a stroke in adequacy with the dimensions of the object. Furthermore, these axes of movement must be carefully sized, because they must be precise (little step movement) and strong (often used). For the matrix detectors, the possibility of scanning in several times by shifting the sensor in width and in height ("mosaic" of images) allows a significant increase of the field. Here still, the precision of the axes of movement must be fitting with the precision of the sensor.

Mechanical parameters such as speed, accuracy, repetitiveness, stability on movements and coding of the location (localization, coordinates resuming to find a defect) must be sized in a coherent way with the parameters of the sensor (spatial resolution, temporal resolution…).

5.4 The families of detectors

The digital sensors can be classified in five families:

1) The Image Intensifiers, where a scintillator screen, followed by an amplification, is coupled with a camera,
2) Scintillator screens coupled with a CCD without amplification,
3) Linar detectors and pixelated flat screens which associate a layer of scintillating material directly in the contact of a set of photodiodes implanted on a substratum in silicon (amorphous (a-Si) in the case of the flat screens),
4) Linar detectors and pixel flat screens directly implemented on a semiconducting substratum (a-Se) which realize a direct conversion of photons X into electric signal,
5) Phosphor plates deliver an image thanks to the phenomenon of photostimulated luminescence (latent image). The image is revealed after a process of optical reading of the screen beforehand exposed.

For the first three families, the conversion of photons X into electric signal is said indirect because of the step of transformation X-visible.

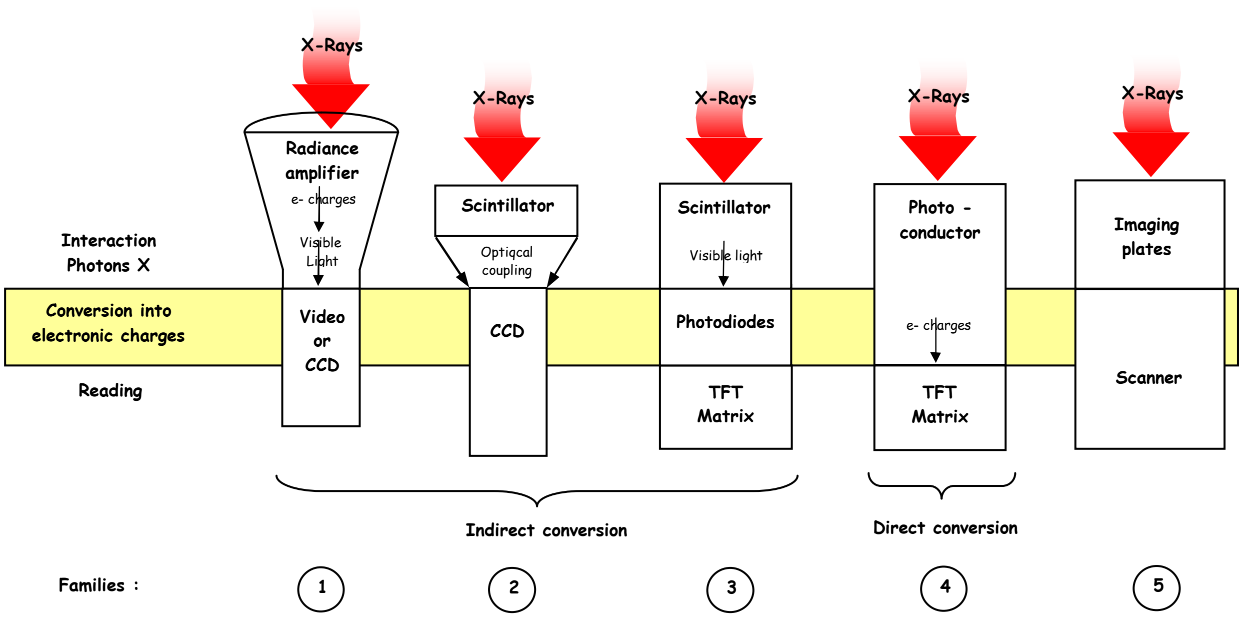

Figure 2 : The families of detectors

The sensors of family 3 are available in a large number of configurations. They are in constant evolution (diversification of the dimensions and the resolutions) and their performances do not stop increasing. They are on the base of the Digital Radiography (DR).

The family 5 of the phosphor plates differs from the previous ones by the fact that there is no conversion in electric loads at the time of the exposure. This fifth family authorizes the acquisition of an image at once. It is the family which is most similar to the film (flexibility and weak congestion). It is on the base of the Computed Radiography (CR).

6 Digitalisation

There are two aspects in digitalization:

- In intensity: the electric signal is coded in a discreet value (on a scale of 2N levels of grey, N taking at present values between 8 and 16).
- In space: the sampling consists in coding in a discreet value the electric signal in space. Image is thus composed of a set of juxtaposed pixels (pixel = picture element).

6.1 The coding of the levels of grey

Digitalization consists in coding a quantity of electric loads delivered by the detector exposed to the photonic radiation in a binary format (continuation of 0 and 1) doing its treatment and its storage on computer be possible. This operation is mostly realized in closer of the detector knowing that transport of the digital signal is easier on an even important distance.

Realized by a circuit of analogical-digital conversion, the digitalization depends strictly on the input characteristics and among the number of coding bits N to this electronic circuit. The intrinsic dynamics of the circuit is defined as the ratio between the strongest signal which corresponds to the value 2N (256, 1024, 4096 respectively for N equal to 8, 10, 12) and the smallest electric signal to which corresponds the value 0.

More important the number of coding levels is, more faithful the digitalization is and less important the error of roundness at the origin of the quantification noise is. The number of coding bits N cans reach 16 even more for the most successful detectors. Several gains on the input signal of the converter can be replaced to keep a sufficient precision for the weakest signals.

6.2 The spatial sampling

The sampling corresponds to the spatial discreetisation inherited from the geometry of detection (weaker will the step of sampling be, more faithful will the acquisition be). This sampling is conditioned either by the movement of the object between the source and detectors not side by side, or by the distance separating the sensitive side by side or assimilated elements of the sensor.

The step of sampling corresponds to the distance between two successive measures and contributes to the definition of the image in the same way as the dimension of the focus and the ratio between the distances focus - object and focus - detector. The ideal step corresponds in the middle of the smallest searched detail. The choice of this step must be coherent with the size of the source, the size of the detector pixel and the magnification.

In other words, the optimal sampling frequency (or Nyquist frequency) must be taken at least twice higher than the highest frequency wished to be detected in the image. Choosing a too low frequency of sampling engenders a phenomenon of aliasing, cause of artefact in the restoration of the image.

Operations of meeting of pixels (" binning " mode) can be available on a great majority of sensors, to accelerate the acquisition of the images to the detriment of the spatial resolution.

7 Numeric sensors

The families described in paragraph 5.4 are detailed below.

7.1 Physical principles

7.1.1 Family 1: Image intensifier coupled with a camera

This type of sensor uses in first an Image Intensifier (vacuum tube) which produces a double conversion. The first conversion X-rays-light-electrons is made at the level of a coat of scintillating material such as the iodide of Cesium (CsI) coupled optically in a photo-cathode, this group (primary screen) being placed in closer of the input window of the tube. Electrons are then accelerated and focused to interact on a second scintillating plate placed between the anode and the output window. This second group (secondary screen) produces the inverse conversion electrons - light photons in order to restore a visible image.

The transport with or without focus of electrons between the input and the output of the tube can be obtained from various manners: by nearness, by electric or magnetic field or by a network of optical fibres (MCP: Multi-Channel Plate).

The coupling of the vacuum tube with a video camera, a CCD or CMOS sensor allows the digitalization of the image at cadence which can reach from several images to several tens of images by seconds according to the conditions of acquisition. The spectre of emission of the scintillating output layer of the tube must have a wavelength in adequation with the camera.

The conversion factor allows to compare the image intensifiers each others. This factor is included between 7,5 and 15 Cd.m-2/µGy.h-1, and corresponds to the output luminance of the tube by unit of dose debit received on the input surface.

The main characteristics of this family are:

- the possibility of working on very weak dose, thanks to the internal amplification
- the possibility of having several fields of images by piloting of the command tensions of the internal electronic optics,
- the possible high frequency of image acquisition (typically 25 or 30 images per second).

The spatial resolution is largely packaged by the impulsionnal response of the scintillating screen, and the field of observation. Values from 1,5 to 4 pl / mm (125 - 350 µm) are common in the center of the field of the twinkling screen.

On the other hand, this solution presents the inconveniences of a strong congestion, a high mass and an important geometrical distortion in edge of field. Grey level differences between the center and the edges are also important.

The improvement is important but in return the electronic noise can strongly degrade the quality of the image. It is the very sensitive detector, which consequently saturates faster. This characteristic can induce a definitive marking of the screen.

7.1.2 Family 2: scintillators coupled with a CCD device

The sensors based on CCD components were the first digital sensors. They associate an optically coupled twinkling layer with a CCD component.

The twinkling layer plays an essential role in the spatial resolution and the efficiency of detection of the detector. Higher the thickness of the coat is, more the phenomenon of spreading and consequently the spatial resolution will be degraded. So the choice of the material, its structure and its thickness depends on the energy domain of the application. The most common materials are the “cesium iodide” (CsI), the “gadolinium oxysulfure” (Gd2O2S) and the “cadmium tungstate“ (CdWO4).

Because of the weak surface of the CCD component, the optical coupling is obtained by means of a mirror and lenses or a network of optical fibres (taper) which allow a reducing factor such as a maximum of light emitted by the surface of the input field to be seen by the CCD component, mostly inside.

The CCD is particularly sensitive, also every element of the device of coupling reduces the number of photons which reaches the CCD and consequently contributes to increase the noise and to degrade the quality of the image. The geometrical distortions and the phenomena of spreading of the light are the consequences of the use of an optical reduction. To get rid of the limitation of the field, it is possible to cover scintillator screen by means of several cameras. It is possible that connecting the images be difficult, but in return association of a large field with a high spatial resolution is allowed.

The thermal noise of the CCD also remains a source of supplementary noise except in the cooled components.

Major interest of this family is the possibility of deporting the CCD component out of the main direction of the high energy applications X-ray beam, and having choice in the most adequate scintillating material.

7.1.3 Family 3 : Indirect conversion flat panels

This technology consists of a fluorescent layer which releases light photons proportionally to the stream of incident X photons. These light photons are detected by a matrix of photodiodes implanted on a layer of amorphous silicon (a-Si). The electric charges generated within every photodiode are read by an active matrix of TFT. A photodiode and a transistor are situated behind every pixel.

Thanks to the atomic number and to the thickness of the fluorescent coats (CsI, Gd2O2S, CdWO4) that can reach few hundreds of microns, this type of detector can be used for applications using energies until 1 MeV. The use at higher energy requires precautions (a protection of steel plate of electronics by armour). A metallic plate (Cu, Al or Ta) enables to play the role of reinforcator.

7.1.4 Family 4 : Direct conversion flat panels

This technology consists of a photoconductive coat mostly in amorphous selenium (a-Se) which releases electric charges proportionally to the flux of incidental X photons. Electrons migrate to the surface of the photo-conductor putted down to an electric field. The collection of charges and the reading of every electrode is performed by an active matrix consisting of a thin coat of transistors with effect of TFT (Thin Field Transistor).

Charges collected by the matrix are exactly localized very under the influence of the electric field applied perpendicularly to the plan of the plate, which confers to this type of detector a very good spatial resolution limited by the size of the matrix TFT. The losses of signal are limited.

On the other hand, the selenium used as material of detection is a very fragile material: it goes off its plate below 5°C and it crystallizes in a irreversible way if the temperature overtakes 50°C. These characteristics impose severe constraints in the conditions of storage and of use of detectors.

Matrix systems using other semiconducting materials (CdTe, HgI2, PbI2) are for the study to cover a larger range of energy.

7.1.5 Family 5 : Phosphor plates

The principle of functioning of phosphor plates is based on the property which has any insulating material to create electric charges under the influence of an irradiation. In scintillator screens described previously, the electric charges re - combine very quickly by generating a light emission. In the case of phosphor plates, charges remain trapped and form a latent image until an external excitement comes to let them out.

The production of a radiographic image is thus made in 2 phases: at first, the screen is exposed under X-rays and the radiological image is recorded in the screen, then the reading is made in batch mode by means of a He-Ne laser beam coming to sweep the screen. A photomultiplier reads the light emitted by the various points of the screen during the scanning.

Materials used classically to realize these screens are the “fluorohalogénure of barium doped with europium” (BaFBr:Eu) or the “bromide of cesium” (CsBr). The typical thickness varies from 150 µm to 400 µm. These screens appear in the classic dimensions of the radiology, protected by cassettes similar to screen-film cassettes. The use of this type of screen brings the advantage to be able to replace the radiographic films in numerous applications. However, the spatial resolution remains lower than that of the film.

These screens use the property of scintillators (such as BaFBr / I:Eu2 + or CsBr) to form a latent image during an exposure to X-rays or gamma rays. During the manufacturing of the twinkling layers, some of the sites of the network of the phosphor normally occupied by fluoride ions and\or bromide ions are vacant sites. These vacant sites are called " centres F + ". During the interaction between the ionising radiation and the scintillator particles, the electrons of the screen are excited to a superior level of energy, creating a positive hole at the level of the ion Eu2 +.

These electrons excited to a superior level of energy are trapped by the F + centers to form metastables F centers (from German farbe: color). This process is not destructive and the latent image so formed remains stable for several days.

The reader scanner is an electromechanical device for the extraction of the latent image, the reconstruction and the display of the radiographic image. We can choose the spatial resolution of the digitalization (typically of 50 µm in 200 µm). As all the digital systems, the image is digitized on 12 bits minimum (4096 levels of grey).

The spatial resolution of Phosphor plates can be improved by optimizing the size of the laser beam, the thickness of the twinkling layer, the morphology and the compactness of the material of the scintillator, as well as by using an intermediate absorbent coat between the phosphor and the support, to absorb backscattering parasites.

The Phosphor plate is scanned by a red laser, typically a HeNe laser. The absorption of energy by the F centres results in the liberation of electrons. The return of electrons released in the band of lower energy comes along with a blue light emission (λ = 390nm).

Its intensity is directly proportional with the number of absorbed X photons or gamma rays by the phosphor screen. The emitted light is measured by means of a photomultiplier, digitized and the radiographic image is reconstituted by the computer. The screen can be then erased by a white light source which provokes the return to the initial state of all the trapped electrons. The screen is then ready to be reused.

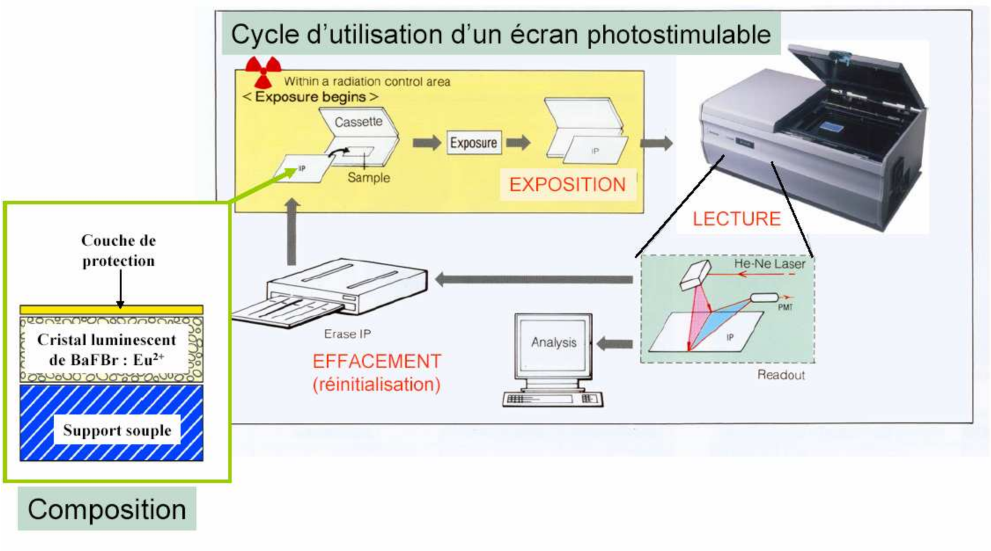

Figure 3 : Principles of reading of a phosphor plate by a scanner

The standard IN 14784-2 details the terms of service of phosphor plate.

Besides the advantages common to all the digital systems, the specificities of phosphor plate are:

- Flexibility and various dimensions (until 35cm x 152cm),
- Possibility of cutting varied forms, limited by the loading capacity of the scanner,
- Portable system facilitating the catching of radiographic images on remote construction sites.

The inconveniences are very close to those of the argentic film, notably in times of manipulation and execution. As such, the time of digitalization and disappearance of the phosphor plate is not unimportant.

The resolutions depend both on the screen itself and on the scanner. They are of the order of 100 µm 400 µm.

7.2 Particular cases

7.2.1 Linear Detectors

Whatever the type of conversion (direct or indirect), detectors also decline in the form of linear camera. The in using interest a Linear Detector Array: LDA lie essentially in the fact of eliminating the backscattering radiation by addition of a collimator and also for a geometry requiring a big width field (superior to one meter).

For the appeal to a mechanics of scanning, which allows to make move or the object or the group “source – detector”, we shall obtain an image. The speed of the movement will be chosen according to the characteristics of the sensor (line integration time and transfer cadence).

This geometry of detection is widely used in the control mechanisms of luggage and big volume containers as well as in the high energy applications (several MeV). It allows to get rid of the radiation diffused by the object and the environment.

7.2.2 Multilinear Detectors

Their principle is close to the previous detector. The detector is a matrix of sensitive pixels and works in TDI (Time Delay Integration) mode: every point of the object is successively detected on several pixels of the detector. The corresponding signals are electrically added in synchronization with the scrolling of the object. As a result, there is an improvement of the signal to noise ratio in square root of the number of integrated lines

7.2.3 CMOS component

Using a CMOS component (Complemetary Metal Oxyde Silicon) rather than CCD allows an important benefit improvement on the factor of completion (sensible surface / total pixel surface) and consequently on the sensibility. The integration of an amplifier at the level of every pixel contributes to improve the signal to noise ratio. The CMOS technology allows to integrate within the sensor of the features of treatment of the digitized image. The CMOS image sensors (CIS or CMIS: CMOS Embellishes with images Sensor) offer certain advantages. The strongly submicronics CMOS process presents naturally an improved holding against radiations.

8 Quality parameters of image

The following figure shows a theoritical plan of the geometry of acquisition in radiography. The distances and the important parameters are introduced:

- d = diameter of the spot
- a = Distance Indication-sensor
- F = Distance Source-sensor
- fg = geometrical blurring

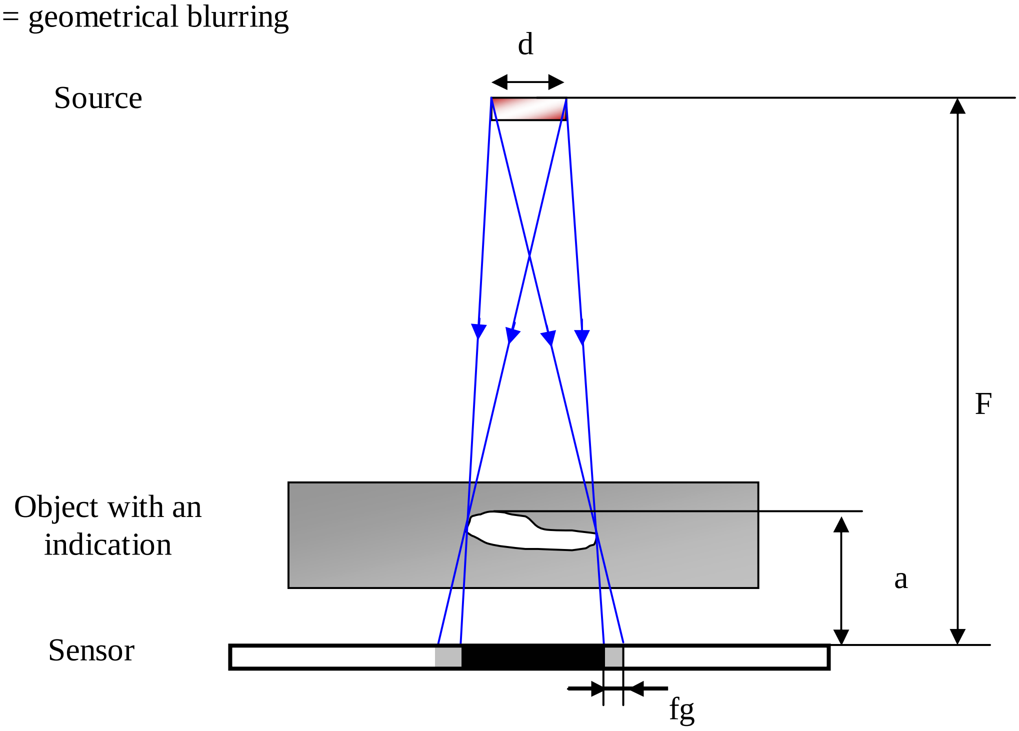

Figure 4 : Radiography acquisition geometry

Distances have a direct influence on magnification, vagueness, scattering radiation and received dose. In particular, the enfeeblement of the direct radiation is proportional in $1/F^2$

8.1 Magnification

The magnification is given by the relation : G = F/(F-a), ...(1)

8.2 Blurring

8.2.1 Geometric blurring

$$fg = \frac{d \cdot a}{F - a} \qquad (2)$$

It is possible to show that fg = d(G-1). ....(3)

The minimization of the blurring results from a compromise with the wished magnification. It is useless to look for a very weak blurring if the spatial resolution of the detector is inferior. In practice, it is advisable to choose a magnification such as the blurring remains lower than the size of the pixel.

8.2.2 Kinetics fuzzyness

This blurring is due to a relative movement of the sensor, the source or the object during the time of integration of the image. The authorized movement must be put in connection with the temporal resolution of the sensor (for example a movement of a half-pixel during the time of integration can be accepted).

8.2.3 Internal Blurring

This loss of neatness is due to the spreading of the radiation in the screen (spreading of the X-rays and the visible radiation in the case of the indirect conversion). Other interactions in the various elements (reinforcating screen, optical) can also contribute to this type of blurring.

8.3 Noises

The dominating noise is the photonic noise. Even if the electronic noise and the diffusion noise are reduced at least, the quantum statistics implies that there will be inevitably a variation in the number of X-rays detected from the source.. There are other noises due to the electronics of the detector and to the backscattering radiation. In a detailed analysis, these contributions must be included. We describe in appendix the various sources of noise.

8.4 Scattering

The detector placed behind the object receives the directly transmitted radiation (carrying information), but also the backscattering radiation by the volume irradiated in general (supplementary dose which does not bring information).

If the detector is taken away from the object (for the same distance source - detector), a part of this backscattering radiation will divide up outside the detector due to the fact that the spreading occurs in all the directions. So the ratio of the useful signal on the total signal increases. The use of a collimator also enables to optimize the detection of the useful signal by reducing the irradiated zone and thus the diffusing zone. It is important to note that all the precautions taken to get rid of the backscattering radiation reduce the received dose which leads to increase the time of integration to have signal carrying information.

The regulation of the magnification is finally made according to the vagueness, to the backscattering radiation and to the resolution of the sensor.

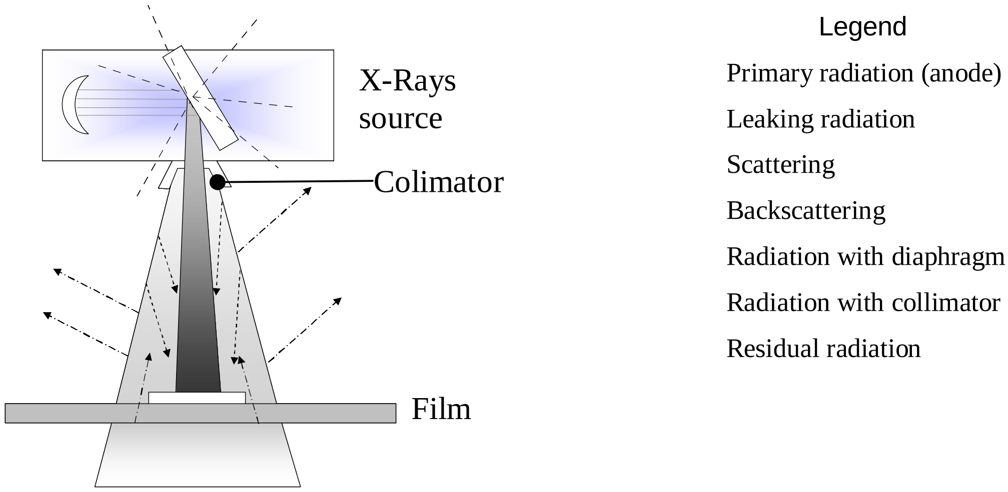

Figure 5 : Radiation types

8.5 Spatial resolution

The notion of resolution in a digital radiography image is bound to the visibility of an element. It depends on numerous parameters: the difference of X-rays enfeeblement between the element and the bottom, the size of the element, the size of the thorough object, the geometry of the X-ray beam and of the dimension of the focus, the size of pixels, parameters of the X-rays exposure as well as certain number of other factors.

For a digital sensor, this notion of resolution is rather different from the resolution of an analogical detector like the film. Indeed, it is always possible to detect an object which is smaller than an image element (pixel), if its contrast is important enough (for example a star in night-sky in visible imaging). On the other hand, it is not obviously possible to separate two distant objects of less than two pixels.

The detectability of a detail is thus connected to two essential notions for the detector: the resolution in contrast and the spatial resolution.

By analogy with the temporal frequencies, we call spatial frequency f the inverse of the period of a periodic motive of which intensity varies in a sinusoidal way. A spatial frequency thus expresses in length or in pairs of lines by unit of length. All the methods of analysis elaborated for the temporal signals can be simply transposed into the spatial domain thanks to this notion of spatial frequency.

The Modulation Transfer Function (MTF) allows to quantify the spatial resolution.

The MTF is the ratio of the output modulation of the system of imaging on the input modulation, for a sinusoidal input modulation, whith a spatial frequency F.

The modulation defines itself as the ratio (max – min)(f) / (max - min)(f0), expressed in the input parameter (for example X-ray irradiation) or to the output parameter (numeric arbitrary units). f0 is the term for the null frequency.

In reality, the MTF can be defined only for linear systems. In the reality, we can speak about MTF for small signals in a restricted domain of linearity, for example for a photographic film.

The MTF(f) is thus the representation of the envelope of the response of the detector to a X-ray illumination modulation of increasing spatial frequency, as figure1 shows below.

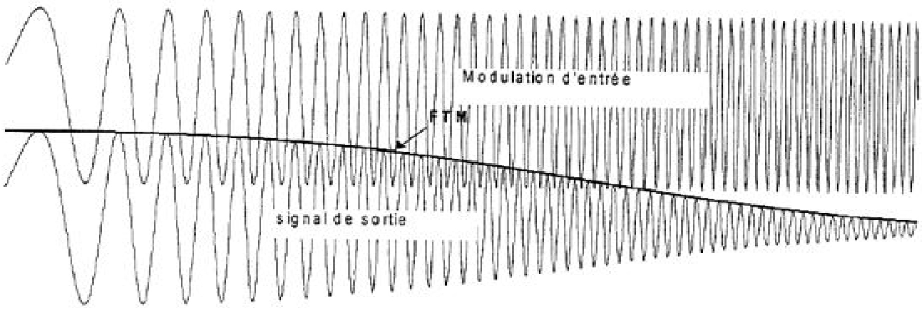

Figure 6 : Modulation Transfer Function.

The FTM presents a considerable interest, because the Fourier analysis indicates that the MTF of several cascade stages in the process of formation of the signal multiplies (successive convolutions). In a imaging system, it will thus be relatively simple to plan the final MTF which is the product of the elementary MTF, For example MTF of the fluorescent screen, the resumption optics, the image sensor. Also, by using the Fourier analysis, the response to some object can be easily obtained if the MTF of the system is known.

The arbitrary nature of the notion of limit resolution appears so clearly: the highest detectable spatial frequency depends obviously on the modulation which we choose as limit of detection.

In a digital sensor, we cannot ignore the effect of the division of the image in elements, pixels. The corresponding mathematical operation is complex and described in all the works on the digital signal treatment.

Let us remember that this process of spatial sampling of an image is authorized only if the image does not contain information (neither signal, nor especially noise) beyond the Nyquist frequency, equal in ½ pixels step.

This can be explained in an intuitive way in the following way: if an object does not spread out on at least one pixel, there are situations where this object is not seen in the sampled image.

The disregard of this law is translated by artefacts called aliasing

- In the signal, the moiré effects on the periodic patterns and the effects of "staircase " on the black / white transitions,
- in the noise, by an important increase of the noise in the frequency interval [0-Nyquist].

The choice of the size of the pixel is thus essential for the adequacy of the detector if necessary, much more than the resolution of an analogical detector, because the size of the pixel fixes an unbridgeable limit to the observable spatial frequency in a digital image.

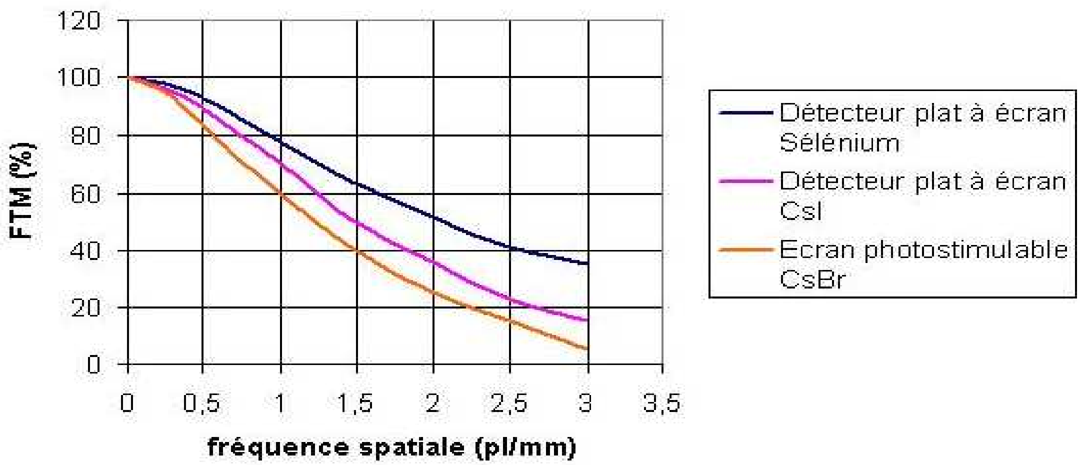

Figure 7 : Different sensors FTM examples

This curve must not be taken as reference of comparison between the sensors. Indeed, the size of the pixel and the thickness of the material converter among others must be taken into account. These measures are valid only for a precise system, and cannot be generalized to all the sensors of the same family.

In the practice, the MTF confronts test cards of variable spatial frequencies, either series of double wire (Duplex Wire).

8.6 Contrast on noise ratio (CNR)

The parameter which is recorded in the image obtained in transmission is the coefficient of linear enfeeblement µ of the projection of the object examined on the detector. This coefficient stands in cm-1 and is proportional in the first order to the electronic density of the material. To be able to be distinguished, a given element has to have a coefficient of linear enfeeblement μe different enough from the coefficient of linear enfeeblement μf of the material.

The coefficient of linear enfeeblement is a function of the incidental energy of the X-rays. By simplification, we shall consider that the X-ray radiation used presents a unique energy, noted E, or while, in the case when it presents a vast spectre, we can assimilate it to a average energy radiation $\overline{E}$.

Let us consider an object presenting a defect and its associated profile representing the number of photons passed on according to the position in the object (cf. figure 8). We consider, in this example a defect of lack of material, which is why the number of passed on photons increases behind the defect.

Behind a homogeneous zone of constant thickness, the number of received photons undergoes a certain fluctuation. This fluctuation corresponds to the higher defined quantum noise.

To this quantum noise must be added photons diffused by the room and by its close environment, which stacks an average signal on the image (fog).

The gap between the average number of transmitted photons behind the defect (N1) and the average number of transmitted photos beside the defects (N2) stands for the contrast C.

The contrast on noise ratio (CNR) can be thus defined in the following way:

$$\frac{C}{B}=\frac{N_1-N_2}{\sqrt{N}}=\left[\frac{N_1-N_2}{N_2}\right]\left[\frac{N_2}{\sqrt{N}}\right]=[\text{Re}\,lative\ contrast].[Signal/Noise] \quad \text{..........................} \quad (4)$$

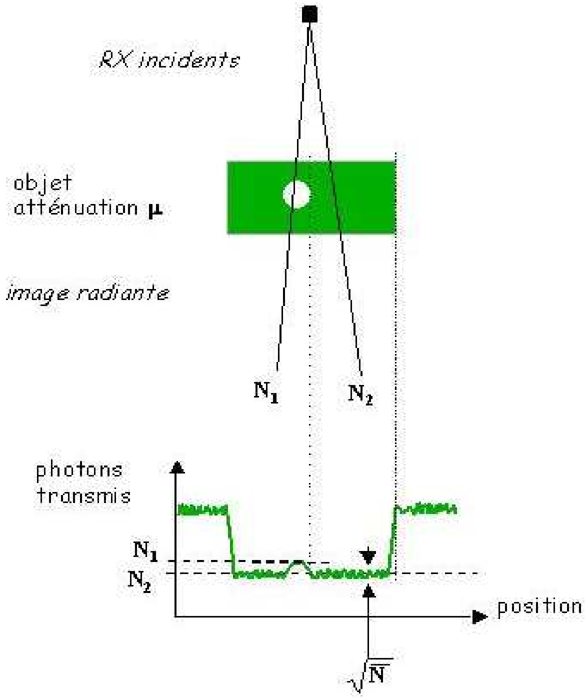

Figure 8 : Defect detection in an image.

So, to detect a defect properly, the CNR has to be the biggest as possible, that is to say it has a maximum contrast for a minimum noise. A CNR equal to 1 indicates a defect flooded in the noise. The CNR can thus describe how easily a defect can be detected. A high CNR indicates a better detectability.

In order to improve the CNR, it is necessary to increase the relative contrast or the SNR or both simultaneously when it is possible. A big relative contrast implies a weak incidental energy of photons (and\or a thick defect). Besides, the SNR increases with the number of photons, that is to say with the intensity of the tube X, but also with the high tension. This is thus often incompatible with a weak energy because then the number of transmitted photons is low.

Optimization of the detectabiliy of a defect is the result of a compromise between a high signal (with regard to the noise) and a high contrast. This optimization is leading to the choice of the best energy for a maximal detectabiliy, for a predefined dose.

The choice of an optical density of 2 on an argentic film corresponds to a maximal slope in the characteristic. It is useful to know or to draw this response curve for every sensor in order to use it in the optimal conditions. It allows to know the necessary minimum grey level to have a signal carriing useful information.

8.7 Sensibility on IQI

The use of IQI on films can be transposed to the digital sensors. This parameter combines at the same moment the spatial resolution and the contrast resolution. Indeed, the wires or the holes of the IQI are a diameter which decreases proportionally to their thickness. So, the detection of a small wire requires at the same time a good resolution and a good contrast. An inconvenience of this parameter is that we cannot deduce when the obtained sensibility is insufficient, if we are in the presence of a lack of spatial resolution or a lack of contrast

In argentic film radiography, the sensibility is visually judged. In digital radiography, it is possible to measure the CNR associated with every wire or hole. The user has to define a criterion on CNR from which the IQI is considered detected.

8.8 Dynamics

Dynamics is the ability of a detector to get signals of very variable amplitudes. The absorption by the object is often considerable, which is translated by a very intense illumination of the detector around the object. Although this zone may acceptably be saturated because it does not contain useful information, it can be necessary to show the edges of the object, which are generally little absorbent. It is also sometimes necessary to detect details of weak contrast of an object presenting a strong variation of thickness. A very big dynamics is thus whishable.

Dynamics is defined as the ratio of the biggest measurable signal on the noise in the absence of signal, the minimum noise being at least the one of the signal quantification.

With a dynamics of 100:1, as in the linear part of a classic film, only defects of some percent will be visible. With a dynamics of 12 bits, that is 4096 levels, a difference of grey about a few per thousand becomes then detectable.

Finally, it is necessary that a local saturation does not overflow on useful parts of the image. In a general way, the saturation is to be avoided every time it is possible (use collimation, masking, conformators).

8.9 *Detection Quantum Efficiency*

The previous paragraphs show the joint influence of the spatial resolution, the contrast resolution and noise on the quality of image. It is not possible to distinguish the performances of a detector by a single number.

That is why a factor of merit, which combines the mentioned parameters above, was defined. It is the DQE : Detection Quantum Efficiency

It is defined as : $DQE(f, dose) = \frac{SNR_{input}^2}{SNR_{output}^2}$ ....(5)

According to the Poisson statistics followed by photons, the **Fehler! Kein gültiges eingebettetes Objekt.** is simply equal among received photons, at all the frequencies.

The DQE is equivalent to a coefficient of absorption: for a proper noiselessly detector, it is equal to the absorption of the X-rays by this detector. For a real detector, it is lower than this value, and deviates from it especially since the noise of the detector is big, compared with the photonic noise.

It cannot be reduced to a number, because it is strongly dependent on the dose and on the spatial frequency. Only while examining the curves of **Fehler! Kein gültiges eingebettetes Objekt.**that we can make sure of the adequacy of the detector if necessary, itself expressed according to the size of the object and the searched contrast.

We can summarize this definition by saying that the DQE is the coefficient of actual use of the X-rays which reach the detector with a dose and a given spatial frequency.

It is about a decisive criterion in medical imaging, for which the dose delivered to the patient has to be the weakest possible. If the dose is not a critical parameter, the DQE can lose of its interest for the benefit of the spatial resolution (or more prosaically of the price). The Figure 9 gives in example the curves of DQE for some detectors used in medical imaging.

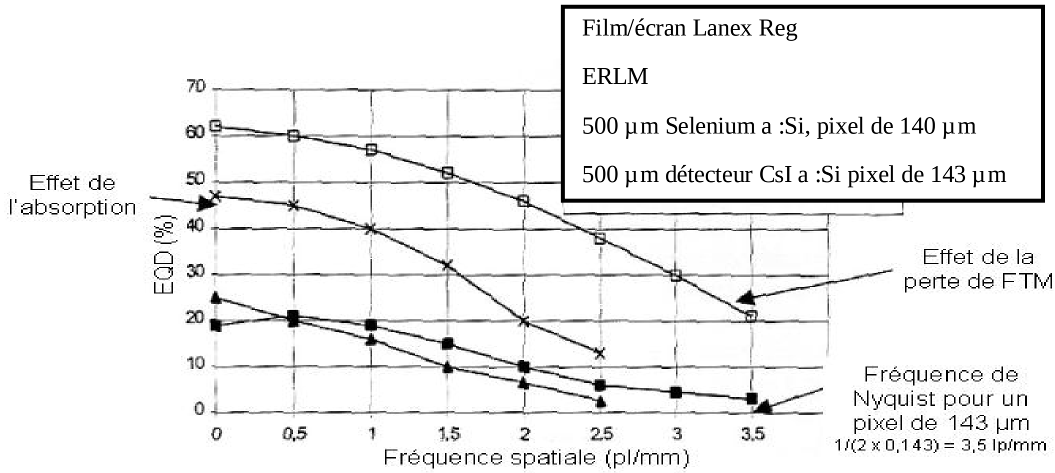

Figure 9 : Quantum Detection Efficiency of different sensors
in the same spectrum (70 kV, 21mm Al filter) and dose (2,5 µGy) conditions.

These curves show the various effects which influence the DQE:

- In very low spatial frequency, it is mainly the absorption which limits the DQE,
- with the highest frequencies, it is the loss of MTF and the noise aliasing which explain the fall of the DQE,
- with the intermediate frequencies, it is the noise of the detector that is responsible for the diminution.

8.10 Persistence

The persistence is seen by a ghost image which overlaps the one of the evolution of the examined object and which fades slowly in the following images. It depends on the material converter and on the family of the sensor. A solution to get rid of it consists in repeating calibrations.

In dynamic follow-up, it is a particularly penalizing factor (trail effect).

Even for static images, the temporal behaviour of a detector is an important element: it is necessary to avoid the past of the detector before the considered image having an influence on the result.

8.11 Temporal resolution

In the case of a pulsed source, it is imperative that the temporal resolution of the detector be adapted to the source recurrence frequency. This parameter is essential especially when the image frequency is high or of the same order as that in the source.

The temporal resolution will have to be compatible with the speed of the observed phenomenon, taking into account the kinetic blurring.

8.12 Synthesis of the characteristics

The advantages of the digital sensors with regard to the argentic film are:

- Significant benefits on consumables, safety and environment (screen, chemics), and on maintenance (simpler on a scanner than on a developing machine),
- Use of the same sources of radiation, the same metal screens as the radiography film,
- Wide range of exposure with a linear relation between the luminescence intensity and the received dose,
- Reduction of the exposure time (in certain conditions) and dose debits with regard to the film
- Treatment and filing of the data.

In the actual case, we suggest a synthesis of the characteristics for each family identified in the following board. These characteristics are liable to evolve with technological developpements.

Table 1 : General characteristics of sensors by family

Performances per category	1	2	3	4	5
Spatial resolution	**125 à 350**	**50 à 500**	**50 à 1000**	**50 à 250**	**100 à 400**
Field of view (mm)	**Φ≤ 300**	**unlimited**	**≤ 400 x 400**	**≤ 400 x 400**	**≤ 350 x 1500**
Linear range of the field of view (mm)			**200 - 1500**	**200 - 1000**	
Effective dynamic (bits)	**≤ 10**	**≤ 10**	**≤ 12**	**≤ 12**	**≤ 10**
Size	**Large**	**Large**	**Small to medium**	**Small to medium**	**Very small (same as films)**
Transfer rate (image/s)	**1 to 500**	**≤ 50**	**≤ 30**	**≤ 10**	**Done afterward**
Specific advantage	**sensitivity**	**Adaptable**	**Resolution & Dynamic**	**Resolution & Dynamic**	**Simple to use = film**
Real-time imaging	**Yes**	**Yes**	**Yes**	**Yes**	**no**

8.13 Monitoring of the performances of a device

The monitoring of the performances of every element of the system joins mostly in the global initiative of checking the complete device. A drift of the device (resolution, contrast, linearity…) will not be necessarily detected on the digital image according to the level of precision wanted for about the controlled objects. Only the definition and the periodic use of standards objects or of adapted quality image indicators allow an optimal monitoring of the performances.

Presently, there are only two standards describing a methodology of system time monitoring:

- the standard EN 14784-1, for the phosphor plate,
- the standard EN 13068-2, for the radioscopy.

In the absence of standard for the other sensors' families, the user can be inspired by these two existing standards to draft a appropriate procedure for his installation.

We will particularly watch the following points, in the same conditions of shootings (energy, debit, collimation, filtering, distances, environment…):

- periodic test on IQI and representative ghosts of controlled objects (measure of the CNR),
- regular measure of the spatial resolution, the SNR
- measure of the field homogeneity

9 Corrections of the sensor (Acquisition pre-processing)

A number of recurring defects are noticed on the images of digital radiography, because of the heterogeneous character of the sensor response. The pre- processing of calibration allows to obtain an exploitable image after correction of all the defects bound to the acquisition device.

The pre- processing will produce an image which we shall call "raw image" containing the corrected acquired information. It is the first archived image.

9.1 Defective pixels correction

Any linear or matrix detector has definitively defective pixels. A map of these pixels must be established at the start and held up to date according to the ageing of the detector. Every image will be corrected from its acquisition, and the value of every defective pixel will be determined by interpolation, from the values of the nearby pixels, or for example with a median filter.

For every application, it will be advisable to determine the various criteria (percentages of defective pixels, adaptations, groupings, restricted zones, etc.) allowing to consider or a sensor as valid or not.

This type of correction is not easily applicable to phosphor plates.

9.2 Thorough review

The thorough review (or non uniformity correction, shading, flat field) is a correction and a compensation of the defects of the acquisition device (sensor itself, optics, amplifiers, constant radiationparasites, heterogeneous or badly centred X-ray beam…).

$$\mathrm{Im}\,age_{corrected} = k.\frac{\left(\mathrm{Im}\,age_{raw} - \mathrm{Im}\,age_{black}\right) - \left(\mathrm{Im}\,age_{thermal} - \mathrm{Im}\,age_{black}\right)}{\left(\mathrm{Im}\,age_{white} - \mathrm{Im}\,age_{black}\right)} \qquad \text{...................(6)}$$

Image raw is the image obtained after integration and correction of the defective pixels, Image black the image supplied in the absence of RX, with a integration time equal to the one of the raw Image, Image thermal the image characteristic of the variations of the signal in time due to a thermal drift of the sensor (even in the absence of signal), Image white the image obtained under RX with maximum flux (however without saturating the detector) and k the normalization coefficient of the image (often the average of the grey levels of the raw Image.).

Mostly, if the shoots are not very long, the thermal noise is very weak and can be ignored. The corrected formula once simplified becomes :

$$\mathrm{Im}\,age_{corrigée} = k.\frac{\left(\mathrm{Im}\,age_{brute} - \mathrm{Im}\,age_{noir}\right)}{\left(\mathrm{Im}\,age_{blanche} - \mathrm{Im}\,age_{noir}\right)} \qquad \text{...(7)}$$

The image of black is sometimes called image offset or zero or dark. The image of black must be redone if the thermal conditions change.

The image of white is sometimes called gain image or compensation or flat field or full flux or light. For a finer correction, we can use a uniform image obtained in average flux. In the ideal, the image of white corresponds to the maximum flux which will be received by the detector during the control of the object. It can be useful to have a uniform thickness in the same material as the object and covering the whole detector, when the conditions of full flux are not obtained in the air.

Furthermore, certain devices present zones of their sensitized surface reserved for the correction of the electronic noise. For example, a line and a column of the photodiodes matrix serve only for estimating the conversion noise (correlated line noise) diodes. This noise is taken into account in the calculation and the depiction of the image.

It is also possible to place an object in the image in order to follow and correct the temporal evolutions of the whole chain(channel) (fluctuations in the source for example).

This type of correction is not easily applicable to phosphor plates.

9.3 Integration on a static image

The integration can be realized in two different ways: by the sensor and\or by the acquisition computer.

We shall rather choose to integrate directly the signal into the sensor during the sampling. The exposure time is chosen so as to obtain the highest possible signal, but without saturation (by staying in the dynamics of the sensor and the acquisition device).

If the SNR is not sufficient or if the exposure time is not adjustable, it is also possible to integrate the signal by computer by adding of successive pictures, all obtained in the same conditions of acquisition. This supposes that the final image will be coded on a number of bits superior to the image delivered by the sensor (16 or even 32 bits) to avoid any phenomenon of overflow.

After this operation of addition, the image can be returned to a coding on 8 or 16 bits (for example because of compatibility with a visualization or exploitation software) but it means lower quality. The distances in the finest levels of grey will be lost.

If n images are added, the SNR will be multiplied by $\sqrt{n}$.

9.4 Integration on a dynamic image

In the case of the radiography of an object in movement, the time of integration has to take into account the time of visibility of the popular defect. The integration of "simple addition " type is possible only if the total time of integration (sensor + computing) is at most equal to the middle of the visibility time of the defect in one particular point of the image. Any superior exposure involves an effect of vagueness and trail on the object in movement in the image.

In "real-time" applications, this type of integration can also involve an effect of jerky images when the frequency of display comes down below 15 Hz.

A "slippery average" integration eliminates this effect of chopped display but not the problems bound to a short time of object detection. In every case, the choice of the weight of the various images will be a compromise between the vagueness introduced by the smoothing and the reduction of the noise.

On a static image, the integration by slippery average during a long time remains less effective than the integration by reminder of the images.

10 Image treatment

10.1 General objectives

Digital radiography images can be affected by the following problems:

- diffuse images,
- lack of resolution,
- high "thorough signal", owed for example to an annoying backscattering radiation,
- lack of dynamics of the sensor,
- weak signal on noise ratio, even very weak,
- information bound to the object or to its environment, annoying for the detection of the indications,

The objective of the images treatment will be to extract the information bound to the searched indication, with the aim of:

- increasing the power of detection of the technique,
- improving the expertise and the characterization of the indications of defects in the image,
- increasing the reliability and the reproducibility of the control.

The images treatment allows improvements on film radiography. It makes measures possible and/or more precise, it allows to resolve particular problems, to interpret simply and automatically series of pictures, to spare time in the interpretation and to make it more "comfortable" for the user. Finally, some functions of the images treatment allow the periodical readjusting and checking up of the sensor.

It is possible to define a region said "of interest" (ROI) of appropriate shape, in which specific processing are applied. It allows eliminating the parts of the image containing some information which might spoil a correct or complete implementation of some processing.

10.2 Various processing

Processing modify more or less deeply the information contained in the image, until its deletion, in order to select a part of the signal judged "a priori useful" and to facilitate its detection and its interpretation. So, we shall produce a series of treated images resulting from the “raw image", every treatment trying to make evident a particular aspect of a part of the signal to the detriment of the others.

10.3 Contrast improvement

When the levels of grey present in the image do not use at the most available dynamics, the histogram of distribution of the grey can be stretched without any loss of signal from 0 to the maximal possible value (according to the mode of coding). This stretching can be linear or follow a law distributing differently the balance between the clear and dark zones of the image so as to bring to light a precise detail. The laws most often applied are logarithmic (gamma correction) or exponential, but any other curve of input – output luminance correspondence can be applied.

Example: let us take a signal, coded on 8 bits, containing levels of grey ranging from 30 to 70. 40 useful levels of grey (70 - 30) are distributed from 0 to 255. This correction allows contrasting the image at the most without eliminating any information.

When the research for the minimum levels and the maximum of the raw image is automatic, if this one contains at least a white point and a black point, it will not be modified by this type of correction. In that case, it is necessary to look manually for the adequate levels.

This improvement of the display is almost indispensable to exploit correctly the big dynamics of the digital images and to detect very fine variations of grey levels.

10.4 Visualisation modes, use of colours

The images are mostly shown in levels of grey. It is possible to use color paddle to represent the various levels, but this custom is not recommended except some particular cases, because it causes a strong artificial modification of the contrasts in the image which can mask information when it is not well mastered.

The various images recorded by an object in movement can be shown, treated or not, in the form of a "movie" with the equivalent of a digital video recorder. This mode of display, which allows to use the totality of the possibilities of treatment in several successive visualizations, facilitates the dynamic detection of very weak variations of signal.

10.5 Linear low pass filters

The value of every point of the image is averaged with those of its neighbours following a matrix of level-headedness of variable size (mostly included between 3 x 3 and 11 x 11, this size being directly bound to the size in pixels of the popular defect). Every point of the matrix can have an identical or variable "weight" according to the distance from the corrected point.

This type of filter eliminates all the information with high frequencies of the image. Unpredictable noise, high frequency spatial noise, is thus eliminated, but all the abrupt variations of levels of grey are also eased. The image is vaguer.

The use of this filter can make impossible the detection of details which are smaller than the window of the filter.

10.6 Non linear smoothing Filters

The amplitude of every point is modified according to that of its neighbours. The points of a matrix (3 x 3 or more) of which the corrected point is the center are classified in order of increasing amplitude. We attribute to the central point the value of the point of a given rank after classification. The most used ranks are the minimum, the maximum and the median rank.

This type of filter can eliminate information with high frequencies of the image. The unpredictable noise, high frequency spatial noise, is eliminated with a median. Contrary to a low shelf filter, the abrupt variations of levels of grey of a size in pixels equal or superior to the median rank are not eased. The image is less vague. All the parasites peaks are completely eliminated without modification of the adjoining pixels.

The use of this filter makes it impossible to detect details which are smaller than the window of the filter.

10.7 High pass filters

As for low pass filters, the amplitude of every point is modified according to that of its neighbours. The Sobel, Prewitt, NW, SW type convolution matrix or equivalent, enable to bring to light sudden variations of amplitude in a very precise direction and eliminate all the variations of amplitude which are not in this direction. In case of weak contrast in the filtered image, the average level can be increased by adding a constant (offset).

The Laplacien type matrix brings to light the strong variations of amplitude, but without notion of direction. This type of filtering, very selective, is only applicable on originally well contrasted images. The information of small size, including the noise, is highlighted well and low frequencies are completely eliminated.

The “raising of contrast” type matrices keep the low frequencies of the image but increase the contrast of the sudden variations of amplitude, without notion of direction. This type of filter is equivalent to the superimposing of a typical Laplacien filter and an uncorrected image.

10.8 Threshold and morphology

The threshold is an operation of binarisation of the image. All the points situated on top, down or between 2 level grey values take the value 1. Other points of the image are taking the value 1 zero.

This threshold goes before all the operations of morphology (counting, squelettisation, détourage, location, selection and characterization of objects) which are made on binary images. It supposes that the image to be treated was "thorough reviewed" and that the only important variations of levels of grey which remain before threshold are very characteristic information to be detected and are not due to variations of thickness or density

It is sometimes necessary to improve the binary image by operations of “closure” (dilation followed by an erosion), of “opening” (erosion followed by a dilation) or of reconstruction. These operations have for main purpose to eliminate parasites "objects", or to modify and smooth the shape of the objects which we wish to select and to characterize (position, dimensions, orientation, shape measures etc.).

These threshold operations followed by morphology are mostly used within the framework of a complete or partial automation, of the exploitation and of the interpretation of the images.

10.9 Management and filing of the data

The protection or not of the data, as well as the time of filing, have to be the object of a specification on behalf of the internal "customer". This last one has to be known at the time of the acquisition of the data.

Except specifications and particular demands, the only archived images are the corrected images obtained after integration, correction of the defective pixels and shading. If we wish to keep images before correction, it is also necessary to keep all the necessary images to make a later correction (images of white, black, thermal, of defective pixels, etc…).

All the meta-data necessary to understand, explain and interpret pictures will clearly be connected with the images. The connection mode is left free since its efficiency is demonstrated.

Examples: information in heading or the back of file, names of files all different and without ambiguity, files kept in precise directories (by object or by activity or by product or in order chronological), documents retailing the procedures of filing of all the data and the management in the time of these data.

The image formats, preferably standard, not compressed will be chosen (examples: TIF, BMP, MADE, RAW, DICONDE). The only accepted compression must be reversible, but they are little effective and thus little recommended. File formats owners are not recommended for the filing.

The compressed formats (JPG, GIF, etc.) will be used only for reports and presentation documents.

From the acquisition, the data are permanently stored in two different physical supports so that a material failure does not pull a definitive loss of the information. The choice of supports depends above all on stored volumes, on the duration recommended by filing and computing standards of moment. Storage for a short duration can be very well done on two different hard disks before a periodic save on another support.

All the means, the equipments and the software, necessary for the later exploitation of the images will be kept.

It implies the guarantee that computers, readers and diverse accessories will always be in a state of functioning, as well as operational systems and software of treatment and of display. For this last point, it is recommended that the most recent software of processing should be able to read and to treat the old data.

The data will be regularly read again and verified during the prescribed period of filing. An update and a rewriting on a more recent or identical support will be made if needed.

The conditions of storage are recommended by the supplier of the support.

11 General principles of qualification of a system

The proposition of qualification has to validate a couple "digital radio device/ object family" to demonstrate that the quality level corresponds to the need.

The tests on objects possessing indications in limit of criteria as well as standards thanks to adapted and fixed ranges will allow to complete the file of qualification based on this group of results.

The qualification bound to radiological controls must be preceded by some precautions of usage. Before proceeding to the qualification, the main stages are:

- Definition of the need, the associated quality level (nature of the defects, the size, the position, the geometry of objects),
- Definition of the characteristics of the device to answer the need:
    - at the level of the source and of the geometry of acquisition (energy, focus, blurring, focus – detail distance, object – screen distance, movement mechanics and number of movement degrees, collimation, filtration),
    - at the level of the detector (type, field, gain, dynamics, resolution, real time or not),
    - at the level of the software associated with the detector (display of the grey levels, calibration, treatment, management and filing),
    - at the level of the piloting software of the mechanics and the source.
- Choice of a system and conditions of acquisition associated to answer the need.

The qualification consists in demonstrating on real defects or representative ghosts that the chosen system answers the need in the chosen conditions of acquisition.

Every qualification will be the object of a report detailing the conditions of examination (including reference objects to be periodically checked), the significant or influential parameters (with the associated tolerances), which it will not be possible to modify without proceeding to a new qualification. In this report also represents the working instruction for the certified level 1operator.

In case of important repair, of modification of the system, the modification of the conditions of acquisition or drift in the time of the performances, the qualification must be redone or completed.

12 Practices of examinations

The digital radiography, by its capacity to realize images in short time and in a repetitive way, authorizes even impossible difficult practices of examination in radiography on films:

- The control of objects in big series,
- the 100 %control of big objects,
- the control with automatic detection,
- the control of devices in functioning and in movement (followed dynamics, ageing, objects under constraints),
- the tomosynthesis,
- the localization in 3 dimensions from some sights and the tomography,
- the construction site control with limited irradiation dose.

On the contrary, certain applications which are easy with argentic film (high energy, reduced accessibility needing a flexible sensor, for very big resolution …) require an adaptation of the digital sensors.

13 Conclusion

This document is a first version of a user's guide intended for the potential users of the digital radiography. The domain of the digital sensors evolving very quickly, a regular update will be made by the COFREND workgroup. Therefore, the characteristics indicated in this document are to be considered as a rough guide. The short-term continuation of the workgroup is the addition of practical appendices handling various types of examination and the monitoring in the time of the installations.

This document could serve as base for the elaboration of one or several standards.