

X-RAYS & QUALITY CONTROL

1 What are X-rays

1.a Generating X-rays

A little more about X ray technology and how it plays a leading role in our daily behaviour, more than people generally know.

When you hear about X-rays, the first thought goes to the medical environment; here we will explain nature and generation of X-rays and how much X-ray technology is widespread.

- **Radiation and radiation sources**

Generally speaking, radiation is an agent which transports energy from one place to another, crossing space and material. The route of such radiation depends on the elements which the energy meets. Two types of radiation can be identified: radiations made by elementary particles which carry energy in the form of kinetic energy (electrons, protons, neutrons, alpha particles, etc.) and electromagnetic radiations which carry energy without particles (radio waves, visible light and X-rays).

Electromagnetic radiation consists in the transportation of energy in the shape of discrete quantities called "quantum" of energy, or photons (zero mass particles). There are different types of electromagnetic radiation: radio wave, microwave, infrared, visible light, ultraviolet light, gamma rays and X-rays. The only difference among these radiations is the quantity of energy of the photon. Two main features of electromagnetic radiations are: their straight trajectory and their capability of crossing material.

The quantity of material that the radiation can cross depends on the composition of the material itself and on the energy of the radiation. Low energy radiations (i.e. visible light) cannot penetrate deeply, but high energy X rays and gamma rays can cross very thick objects. These two features (trajectory and penetration) are specially underlined in the radiograph analysis. When X-rays penetrate an object, some of them interact with the object itself, but the main part of the beam crosses the object and (when it strikes an X-ray sensitive surface) generates an image which can supply dimensions, structure and composition of the penetrated object.

- **X-ray generation**

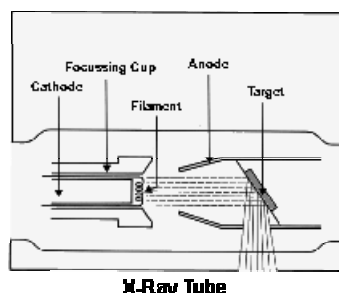
X-rays derive from electrons being decelerated when penetrating an object. In an X-ray tube this process is controlled and electrons are accelerated in order to reach high speed before hitting a "target". The interaction between electrons and atoms in the target determines X-ray generation.

The total energy of the electrons will be converted in X photons and heat. The X-ray generation has a low efficiency ratio and only 1% of the kinetic energy (produced by the strike of the electrons) becomes X-rays, the remaining energy turns into heat. Due to the high temperature, a liquid or air cooler is required.

- **X- ray tube structure**

As illustrated in the picture here below, an X-ray tube is composed by a glass bulb under vacuum, containing a cathode and an anode. Inside the vacuum area, electrons are created by the cathode and accelerated towards the anode. The electrons reaching the target have different energy depending on the voltage on the tube at the moment they have been accelerated.

X-rays are produced when these electrons strike a point of the target which is called focal spot. By shaping the cathode in a specific way, electrons can be sent to the target in a way that the focal spot has desired shape and dimensions. The smaller the focal spot, the higher the resolution of the object in the resulting image.



X-Ray Tube

1.b Generating images

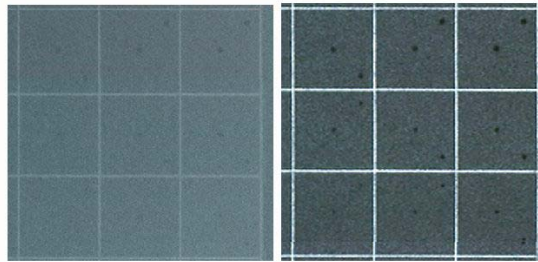
X-rays are not visible and they travel at the speed of light. X-rays cannot be visualized by means of a lens or prism, but an X-ray beam can be detected by special materials capable of converting the X-ray's wave length into visible light.

This brings us to the principle of an X-ray system:

the X-ray beam (coming from the tube) strikes a sensitive surface which can detect its intensity. This surface, which at the beginning of X-ray technology was an X-ray radiograph, is now obtained thanks to various and very sophisticated technologies.

Starting point is the interposition of an object between the X-ray source and the sensitive surface. X-rays are photons similar to visible light, only they have higher energy and lower wave length. Visible light cannot penetrate an object due to its thickness, whereas X-rays can thanks to their energy.

Now it is easier to understand why in an X-ray radiograph, when an object is positioned between the X-ray source and a sensitive surface, dark zones and bright zones can be seen; zones which are exposed to X-rays are the dark ones. This means that different zones receive different energy intensities.



This shows also that when the quantity of material exposed to X-rays is higher, because of a thicker object or a denser object, the quantity of X-rays reaching the sensitive surface is lower. For example, in medical X-rays, in an X-ray of bones, the bones appear brighter than the other parts of the body, which are not calcified like the bones.

1.c Digital X-ray imaging

For almost a century traditional radiography used sensitive films to detect X-rays and, by means of special chemical agents, created images meant for diagnostic purposes.

Recently only, use of new electronic technologies in place of those films has become technically and price-wise possible, for visualization, recording and transfer of images.

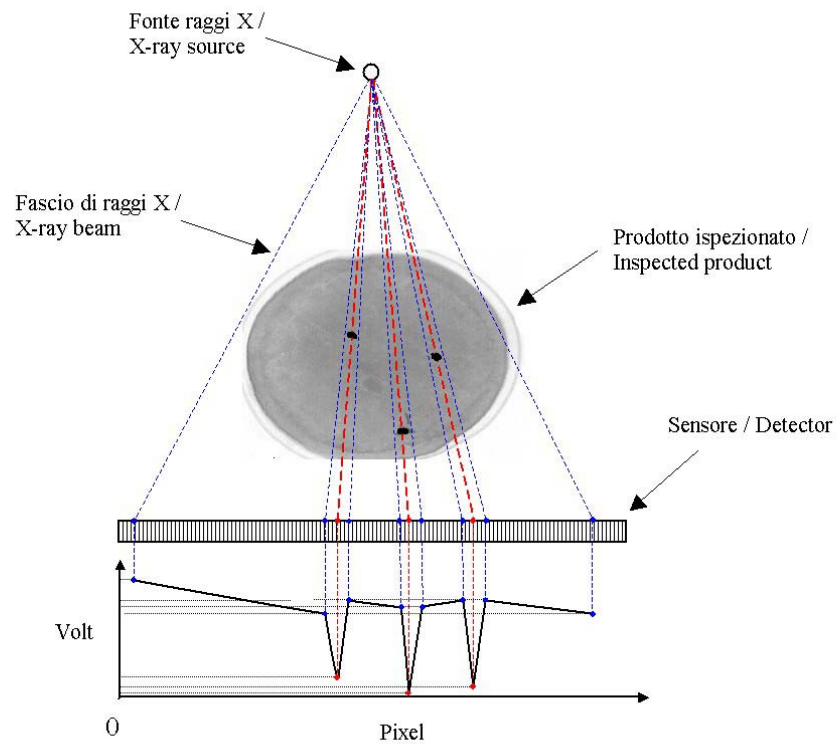
Furthermore, in the very last years, a radically innovative possibility has become reality in the field of image processing: linear and matrix X-ray detectors.

Linear detectors (512 pixels, in other words 512 detector elementary units, having an area of 0.4 x 0.4 mm) allow to receive 512 linear X-ray detections, whereas a matrix detector (512 x 512 pixels) can detect 512 x 512 X-ray signals per square area unit. Thus, quality of the images is greatly improved.

In a digital image, such signals, before generating an image, are converted from analog to digital, in order to obtain a set of discrete values which can be represented as final image.

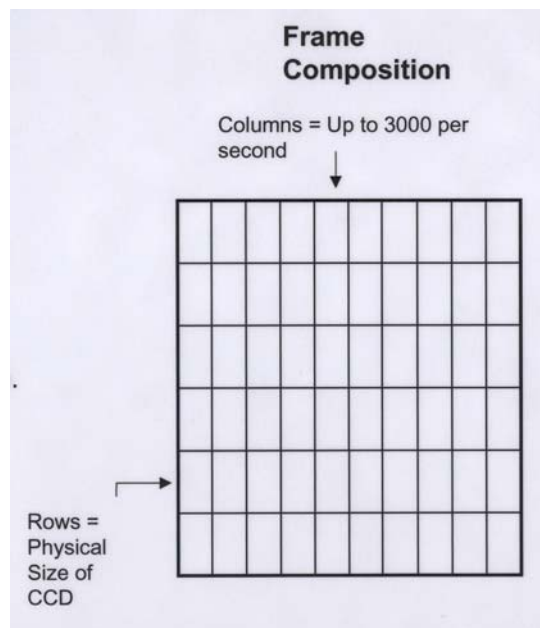
The picture here below shows the X-ray image acquisition process: an X-ray beam crosses an object having dense and non dense areas; the beam then reaches the pixels of the detector, which originally have a zero electric status. Due to the energy of X-rays, each pixel transmits a discrete value indicating the quantity of energy received.

Obviously, if the X-rays cross a non-dense area, the pixel receives a high quantity of energy which is converted into a strong signal whereas, if the X-rays cross a dense area, the pixel receives a low level of energy which is converted into a weak signal.



The information coming from sensitive elements (CCD) is stored in computer memory via an acquisition board. The electronic board builds a matrix of rows and columns: rows are equivalent to the physical size of each corresponding CCD, and columns are formed by gathering information from each corresponding CCD in a time slice.

A machine is capable of up to 3000 lines per second, generating a very high resolution image in computer memory.



2 Why X-rays

2.a X-ray advantages

Every year food and pharmaceutical manufacturing companies experience contamination in the final product that creates unsatisfied customers and injuries, leading to product recalls, to losses in sales and in market shares and to law suits.

Furthermore, X-ray equipment is a multi purpose product, as it performs various functions typical of other machinery used for quality control purposes, therefore making it cheaper than alternative inspection technologies:

- the metal detector, an electromagnetic induction device capable of detecting metal only.
- the check weigher, capable of detecting under weight goods; it is based on the control of the weight of a product, given an average weight.
- optical inspection system, capable of inspecting transparent products and containers.

2.b X-ray performances

X-ray inspection allows quality control tasks that cannot be performed by other technologies:

- type of packaging: any, metal container are not a problem
- type of product contents: any (density, temperature, salinity, humidity of product are not a problem)
- detectable contaminants: metal, glass, stone, bone, fruit pit, high density plastic (PVC), high density rubber, ceramic. In addition, air bubbles and dense areas are detectable
- detection performances: highest on similar detectable contaminants such as stainless steel
- other detectable product features: under/over packaging or filling, missing product (weight), missing items in package, broken parts, non conforming shape

	Metal detector	Optical control	Check weight	X-rays
Packaging types	Non metallic	Transparent (glass - plastic) without labels	All	All
Products inspected	All	Uniform and transparent products	All	All
Detectable contaminants	Metal	High contrast compared to product and glass	Not applicable	Metal, glass ⁽¹⁾ , stone ⁽²⁾ , bone ⁽³⁾ , fruit pit, high density plastic (PVC) ⁽⁴⁾ , high density rubber, ceramic, air bubbles or dense areas of the product
Products detects	Not applicable	Flat glass	Not applicable	Flat glass, quality in package and missing item
Level control	Not applicable	Not applicable	All	Precision inspection for under/over fills

Where the contaminant density is significantly greater than the product, these may be detectable by X-rays. However, it is important to remember that, in general, contaminants will be embedded within the product, and will therefore displace the equivalent volume of material. This will have an adverse effect on the detect ability, compared with applying the contaminant externally to the product.

(1) Glass: There are many types of glass, and the type of glass will affect the detection performance. For example, "lead crystal" glass, will appear to the X-ray system as dense as steel.

(2) Stone: There are many types of stone (rocks). The factors that affect the detectable of stone are: the porosity, the specific gravity and the atomic constituents. Most normally occurring rocks would contain silicon, calcium, potassium, sodium and similar materials. These are mainly "second row" elements in the periodic table, and hence would be detectable with "mid sensitivity" i.e. say, 2.0 – 2.5mm. However, material containing metal ores would appear virtually as dense as a metal.

(3) Bone: the mechanism for the detection of bone is the resolution of the calcium atoms in the hard bone. Soft bones, such as the keel bone in a chicken are not normally detectable. However, chicken rib bones, and fan bones can be detected. Generally, land animals (e.g. pork, beef) will have dense, calcified bones.

Again, porosity is a factor in the detection of bones: a very porous bone is very difficult to detect

(4) Plastic: many plastics would normally only be detectable on the basis of density differential. These include:

- Polyethylene (PE) – this contains C and H atoms.
- Polycarbonate – (Makrolon, Acrylic) – this contains C, H and O atoms, as with the food matrix.
- Polytetrafluoroethylene (PTFE, Teflon) – this contains C, H and F (Fluorine – atomic number 9).

Periodic Table of the Elements

	1	IA																		2	0	
1	H																				He	
2	Li	IIA	Be																			
3	Na		Mg																			
4	K		Ca	IIIB	IVB	VB	VB	VIIB	VII	IB	IIIB	IIIA	IVB	VVA	VIA	VIIA						
				Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr			
5	Rb		Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe			
6	Cs		Ba	* La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn			
7	Fr		Ra	+ Ac	Rf	Ha	106	107	108	109	110											

	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	
* Lanthanide Series	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu								
+ Actinide Series	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr								

Limits:

X-ray inspection does not allow detection of foreign bodies such as:

- insects
- wood
- paper
- hair
- low density plastics
- thin aluminum foil

3 On line X-ray inspection

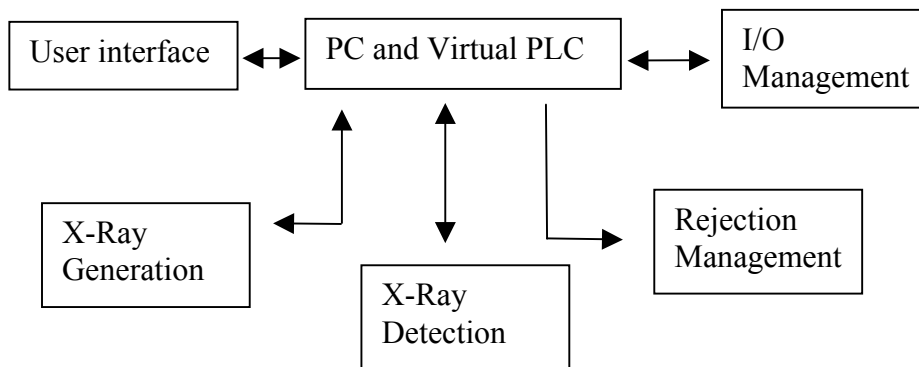
3.a Equipment structure

3.a.1 Control

The X-ray system for quality control uses a Pentium PC to manage the detection process and all the functions of the system. The picture below shows the general layout of the Inspection Unit highlighting the main interactions between the basic elements of the system. In particular, the PC and the VIRTUAL PLC carry out all the main processing and control phases as well as interfacing with the other elements of the unit.

The user interface allows to modify the setup parameters of a product elaboration and change the status of the system. Except for extraordinary repairs, user intervention on the machine is restricted to the user interface.

The Virtual PLC informs the user interface of any alarms or faults on the inspection line. The User interface and Virtual PLC exchange information regarding the characteristics of the type of product to be inspected in order to adapt line status to the product. Concerning timing, motor speed, reject action, etc. (I/O Management) and the status of the interface (operating, in maintenance mode, in automatic mode) other signals are provided for calibration of the detector. Another important signal exchanged between the PC and Virtual PLC allows management of faulty product reject.

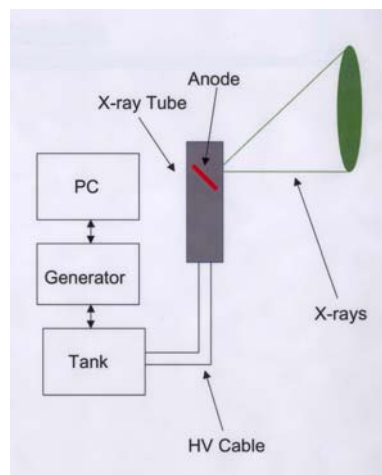


3.a.2 X-ray generation

The process of X-ray formation starts when a signal is sent from the PC to the X-ray generator containing information necessary to set power level and frequency output of the X-ray generator.

When the signal arrives to the generator, the X-ray generator output will be again amplified, and it will be sent to the X-ray Tube via a high voltage cable.

When the high voltage signal strikes the target (Anode) in the tube, X-rays are emitted.



3.a.3 X-ray detection

X-ray energy is received and processed using a detector.

The sensitive element which receives X-ray energy, within the detector, is called CCD (Charged Couplet Device), which transforms X-ray energy into an analog output.

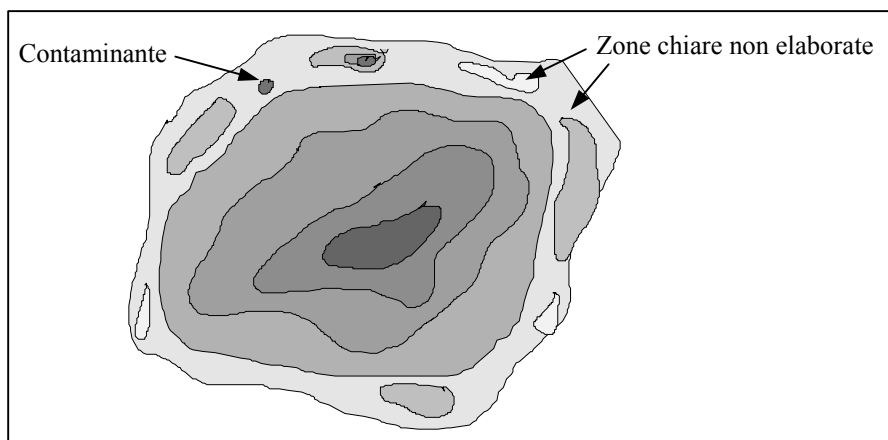
The analog output is sent to an Analog to Digital converter (ADC) and a number (equivalent in the grayscale to the amount of x-ray energy received) is generated.

The amount of X-ray energy a contaminant absorbs is relative to its density and size. Looking at these grayscale readings it is easy to understand that there must be a contaminant in the product, because the grayscale value in the body area remarkably decreases.

3.a.4 Image Processing

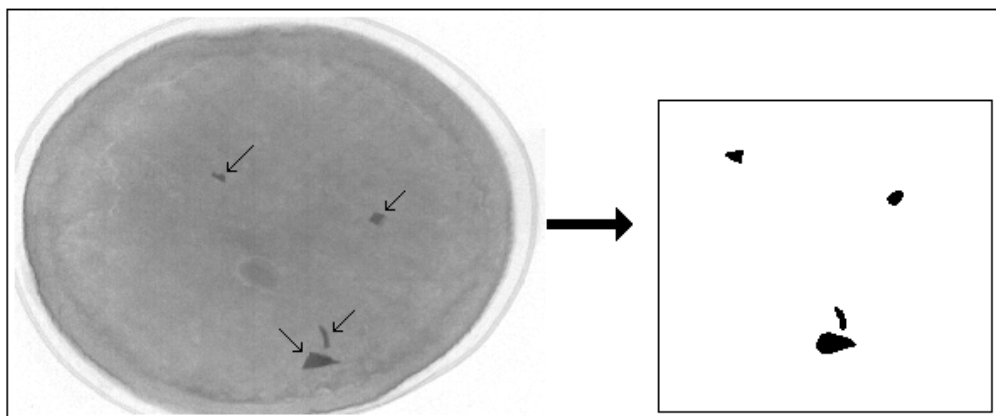
The general processing parameters of the X-ray detection are used to find zone of the object with have different dense value from the average value. In this zone usually we can find foreign body.

The very light zones of the image (moving from the product to zones external to the product) are generally not very homogeneous from a photometry point of view (dark/light anomaly variations), and these irregularities could lead to erroneous pinpointing of contaminants.

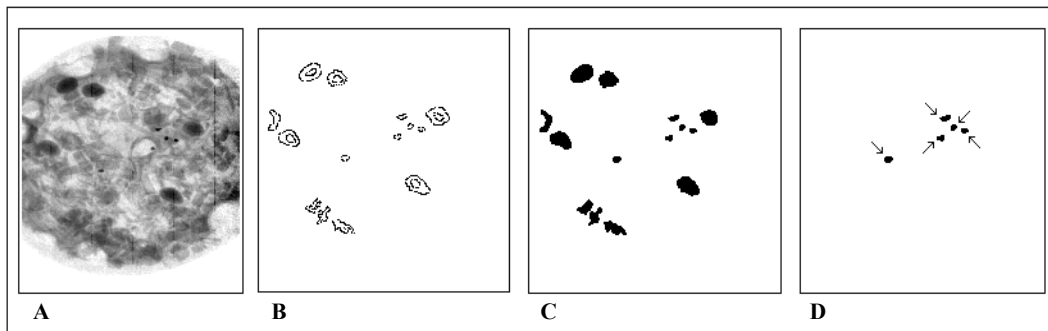


1. Processing methods (algorithms) based on the **analysis of the photometry value** for single image pixels generally allow medium or large sized contaminants or contaminants with high contrast (metal) to be pinpointed.

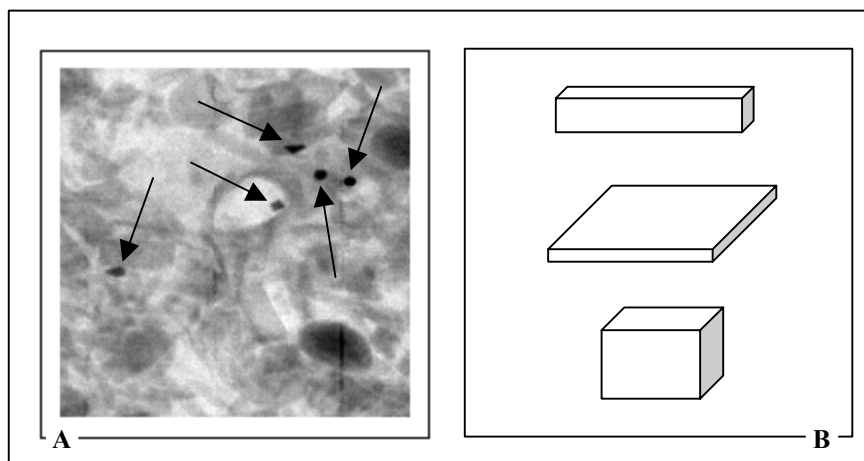
It is important to note that, once the threshold level has been defined, all pixels with a photometry value less than the threshold value are considered anomalous pixels, but only those that meet very precise photometry and morphological conditions are actually considered pixels corresponding to contaminants.



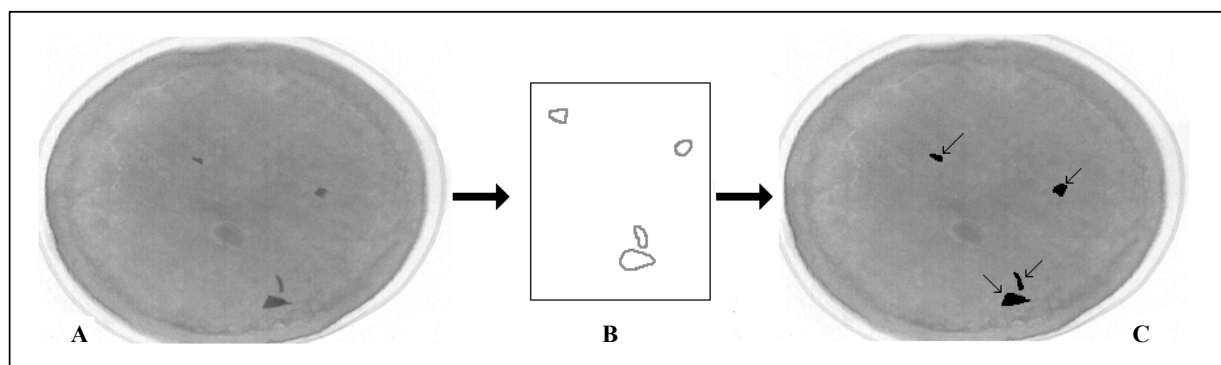
2. Processing methods (algorithms) based on **the analysis of the photometry contrast** for single image pixels generally allow medium or small sized contaminants or contaminants with quite high contrast to be pinpointed.
 All pixels with a photometry contrast value less than the threshold value are considered anomalous pixels.



3. The processing method (algorithms) based on **the analysis of the photometry gradient** of the pixels in the image generally allows contaminants with quite a high contrast with respect to the image to be pinpointed, regardless of the size of the contaminants.
 In addition, the gradient method also allows contaminants with little contrast to be pinpointed, provided they are characterized by angular surfaces or have fracture plains that are perpendicular to each other (see figure underlying).

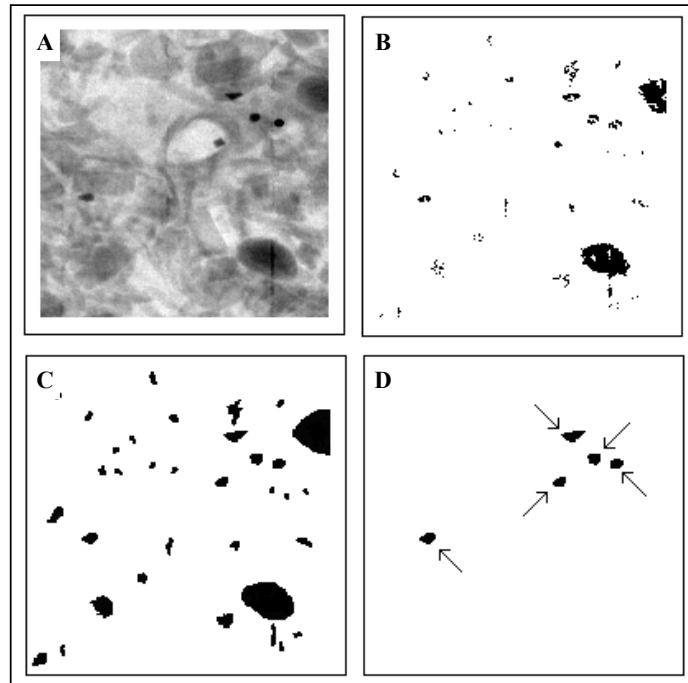


The figure shows the main steps involved in the gradient method: starting with the image of a certain product, the photometry gradient value for each pixel is determined, and all pixels with a gradient greater than the parameter value are considered anomalous pixels. The anomalous pixels pinpointed in this way are used to construct groups of anomalous pixels, and all the anomalous groups thus defined with specific photometry and morphological characteristics are considered contaminants.



4. **Analysis of the contrast value** for dark groups is a very powerful algorithm, capable of pinpointing a vast range of small and medium sized contaminants, even with little contrast.

Starting from the individual dark pixels pinpointed, the system automatically constructs dark groups of which the dark pixels are a part, based on a certain number of photometry and geometric rules, as shown in figure. For each dark group the photometry contrast value with respect to the zones adjacent to the image is then determined, and all groups with a contrast value greater than the parameter value are considered contaminants.



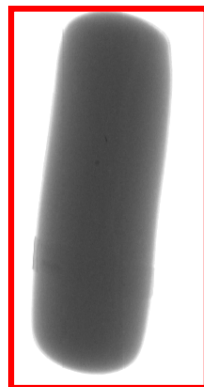
Detectable products features

Contaminant detection performances depend on the following product characteristics : thickness, homogeneity, density

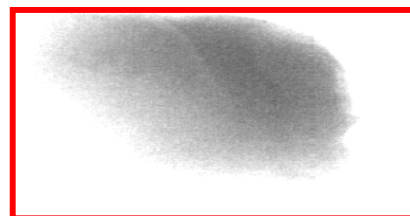
Varying thickness:

When homogeneity and density are the same, a thick product is more difficult to inspect compared to a thin one because the former creates a darker image than the latter; this happens because the x-ray energy which results on the detector (see previous paragraphs) after crossing the thick product is less than the energy which results on the detector after crossing the thin one.

Thick
cheese

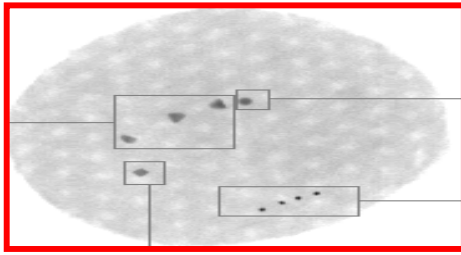


Thin cheese

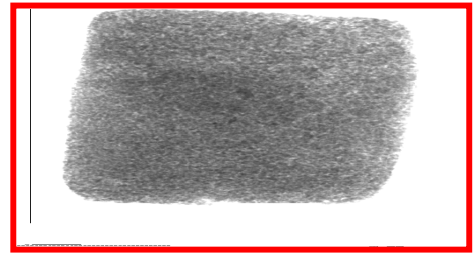


Varying homogeneity:

When thickness and density are the same, an homogeneous product is easier to inspect than a non homogeneous one, because the former creates an image with less "noise" than the latter. In fact a change of homogeneity can deceive the inspection system and inducing to detect a contaminant.



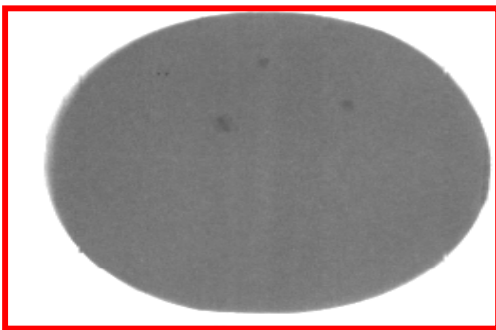
Hamburger



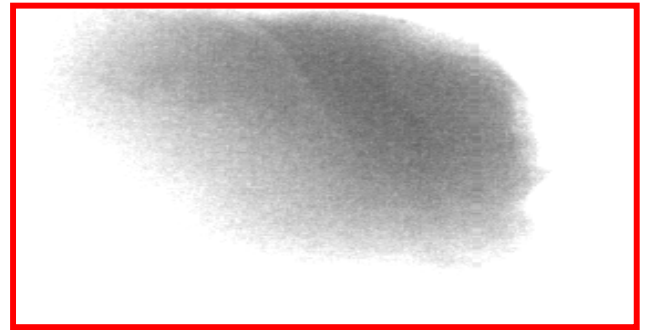
Bacon

Varying density:

When thickness and homogeneity are the same, a product with higher density is more difficult to inspect compared to a less dense one, because the former creates a darker image than the latter; this happens because the x-ray energy which results on the detector after crossing the higher density product is less than the energy which results on the detector after crossing the lower density one.



High density cheese



Low density cheese

3.b Machine communications:

3.b.1 In line

X-ray machines are equipments are completely compatible and can be easily be connected to the customer's production line.

Installing an X-ray machine does not mean revolutionizing the production line, but simply adding a final quality control.

3.b.2 Remote

New technologies allow the monitoring of information coming from the inspection system via a single remote workstation (even for more than one equipment on the production lines of the same factory):

- monitoring of the system status
- possible alarm signals
- production statistics

It is not possible to modify the system status.

Furthermore, thanks to the remote control kit, a skilled technician can take over the control of the inspection system, thus avoiding him to physically visit the customer premises.

4 Range of applications

Dylog is able to provide the most extensive range of solutions for on-line non-destructive quality control via X-ray technology, at the end-of-line stage of the manufacturing process: the DYXIM Series, Dylog X-ray Inspection Machine, is in continue evolution in order to modify in the best possible way the customers' needs.

- Food & Beverage
- Pharmaceutical
- Others

4.a Food & Beverage

Has been the main market since the beginning: nowadays, DYXIM machines provide a solution for:

- any packages: soft and rigid, metal and non metal
- any shape and dimension
- any product

Dyxim FB (Flat Bed) for soft packages, bulk food, pouch, tray, box, carton: allows the detection of many contaminant types

Dyxim S (Single) and **Dyxim D (Double)** for glass jar, bottle, metal can, brick pack: allow the detection of many contaminant types

Dyxim T (Top View) for small glass jar, tin: allows the detection of many contaminant types

4.b Pharmaceutical

A new market recently expanding, where DYXIM solutions have proven to be the only capable of almost 100% reliability in detection of very small contaminants in small containers, such as glass vials and ampoules.

Dyxim FB Pharma (Flat Bed): designed for the inspection of container like blister, pouch, glass and plastic vials with any products.

Dyxim S Pharma (Single) and **D Pharma (Double):** designed for the inspection of container like small medicine bottles, with any products.

4.c Others

Along the lines of various manufacturing processes, specific measurement tasks or quality control of the materials may be required. Some recent applications of the Dyxim system are:

- high precision tools positioning: **Dyxim FB 56, FB 61 e FB 70**
- inspection of pearls: **Dyxim FB Wide**
- detection of metal contamination in clothes with metallic parts: **Dyxim FB Wide**
- detection of presents type in the Easter's eggs: **Dyxim FB 56, FB 61 e FB 70**

5 Safety

The design and construction of X-ray inspection system must be done always considering the safety for the operator and for the inspected products.

- Operator

The operator utilizing the X-ray system must be sure to not run any risk due to the X-ray radiation during its normal activity.

- Product

Inspected product receives a very small X-ray quantity and for a very limited period, therefore there are no problems for its introduction on the market and for the final use.

5.a Operator

Dylog certifies the DYXIM X-ray machine to be compliant with European Community directives: 89/391, 89/654, 89/655, 89/656, 90/269, 90/270, 90/394, 90/679 on work environment health and safety. Moreover Dylog complies with 80/836, 84/467, 84/466, 89/618, 90/641e 96/29 on ionizing radiation radioprotection.

Operator safety is guaranteed on DYXIM units due to the fact that:

- an over dimensioned protection system grants the respect of the international rules for the manufacturing of the ionizing equipment and certifies the X-ray leakage lower than the severe limits settled by international directives: all units are lead-lined and have external protections at the in-feed and out-feed of the inspection area;
- when a machine is open, in order to access internal areas (i.e. for the normal cleaning), x-ray production is immediately cut off.

5.b Product

With reference with hygiene and the treatment of food products, the 93/43/CEE and 96/3/CE have been adopted (prompted by the criteria of the HACCP - Hazard Analysis and Critical Control Point – introduced by the FDA -The Food and Drug Administration -) as the basis for all discussions on food safety and prevention against dangers associated to food absorption, also for the X-ray system manufacturers for the quality control of food products.

The limit recognized by FDA as not dangerous is

$$1 \text{ KGy} = 10^9 \mu\text{Gy}$$

Dylog certifies the Dyxim machine with value 1.000.000 time lower than the limit allowed by FDA.

To limit the level of absorbed X-ray energy on inspection units:

- the product is exposed to X-rays for a very short period;
- a special collimator is used to physically reduce the quantity of X-rays that may reach the product;
- X-ray energy can be kept very low thanks to the use of very high sensitivity detectors.