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Contrast Enhancement on Radiographic Films Using Low Energy X-Ray Transmission Instead of Light

Elicardo Goncalves[1], Lucasda Costa[3], Roberta Leitao[2], Davi Oliveira[3], Luis Oliveira[3], Ricardo Lopes[2] and Marcelinodos Anjos[3]

[1]Federal Institute of Rio de Janeiro – Campus Paracambi, Paracambi, Brazil
[2]Nuclear Instrumentation Laboratory, COPPE, Federal University of Rio de Janeiro,Rio de Janeiro, Brazil
[3]Physics Institute, Rio de Janeiro State University, Rio de Janeiro, Brazil

***Corresponding author:** Elicardo Gonçalves, Federal Institute of Rio de Janeiro – Campus Paracambi, Paracambi, Brazil, E-mail: elicardo.goncalves@ifrj.edu.br*

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Abstract

Radiographic film has a traditional way to be visualized and digitized: the light transmission. The silver concentration is assumed to be proportional to the optical density, and consequently, is the responsible for image contrast. But a previous work showed a limitation on light transmission to measure silver concentration in radiographic films, suggesting measure it directly by x-ray fluorescence of silver, mapping it point by point. While doing the measurement with an industrial XRF mapping equipment, it was found that the fluorescence of the material of holding plate can also produce more image contrast than light. This work aims to show that not only XRF, but also x-ray transmittance of characteristic x-ray could overcome the light measurement limitation. This experiment could be thought like a single energy radiography of the film itself and could be use in specific case on other materials.

Key Words: Radiographic film; XRF mapping; radiographic image; singe-energy beam;

Introduction

Radiographic films image is measured and digitized by means of optical density [1, 2]. When exposed, the emulsion layer of radiographic film creates sensitivities sites. These sites are start points for a chain reaction that turn silver halide grains into metallic silver during the development. As the metallic silver concentration of a part of film is proportional to its exposure, the image is formed by the contrast between different exposures in different parts of the film. Optical density is defined in terms of the ratio between an incident light beam intensity and the intensity of the beam that cross the film. This crossing intensity is proportional to a probabilistic chance, and it depends on the film thickness and the crossing section for the light. The cross section is proportional to the concentration of light blocker molecules. Metallic silver is an efficient light blocker, so, silver concentration is considered proportional to optical density. It means that, the more exposed a region is, the less light crosses it [3-6]. But a previous work has shown a limitation in light measurement while digitizing or even visualizing radiographic films [7], suggesting other ways to do it. The optical density is not fully proportional to silver concentration as considered, because of a limitation in low intensity values, which means high exposure regions of the film can´t be accurately measured [8]. The background light and the electronic noise makes the weak light beam that crosses an overexposed film be not enough to be distinguished. Of course, it could be improved increasing the light intensity, but it would demand larger detection ranges, and there will be always a light intensity in which it happen. It causes a hidden image that is revealed when the silver concentration is read by another method [7]. A Mathematical model for its behavior showed that, in some cases, almost half of contrast image range is hidden in light measurement [8]. Equation 1, for example, shows how it works for a specif odontologicalfilm, and figure 1 show its graph.

$$OD=\log\left(\frac{4495}{4495^{\left(-22{,}9\left(1-e^{-0{,}0043X}\right)\right)}+0{,}0176}\right)$$

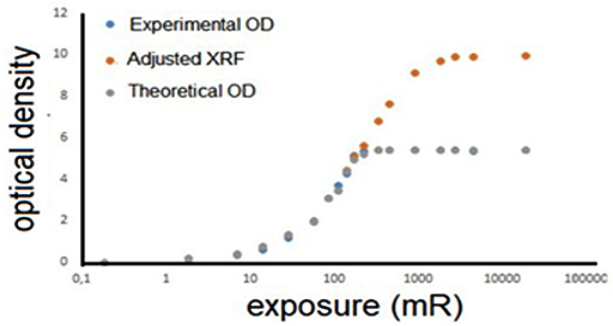

Figure 1: OD (experimental and by equation 1) and XRF measurement x log (Exposure). XRF behaves like the total OD range without limitation [8].

Where OD is optical density and X is the exposure value. The equation 1 was build to reproduce a film considering the limitations. The 0,0176 is the ε value, equivalent to the noise in light measurement. When it is equal to zero, there is no limitation.

when ε = 0, film equatiom behaves like XRF [8]. It could be seen in figure 2.

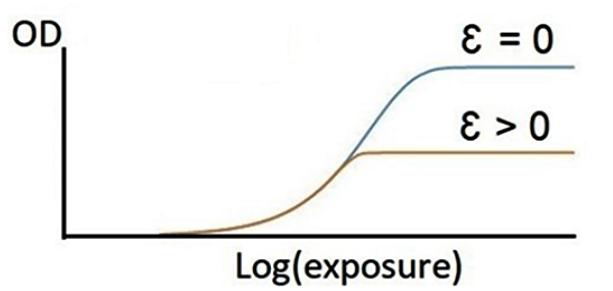

Figure 2: OD x log(Exposure) by equation (8). When ε > 0, the saturation is in low values, hiding a significant range from characteristic curve [8].

X-ray fluorescense (XRF) is a direct way to measure silver concentration. It is also nondestructive, fast, efficient and could be made in little spots [9]. XRF is based on characteristic x-ray photons. These photons are emitted when ionizing radiation produces a vacancy in the lower energy electronic layers of an atom from the sample. To occupy this vacancy, an electron from a high energy layer emits the difference between energies in form of a photon. Because of different electronic distribution, each kind of atom has specific characteristic energies. With a detector that can distinguish energy, it´s possible to find what materials are in the sample. If two points have different counts for a characteristic photon energy, it means that each point has different concentration of the material which emits this photon. Despite the statistical fluctuation, which is inherent to ionizing radiation, the number characteristic x-ray photons for a specific material produced in the sample is proportional to the concentration of this material [9]. Because XRF results are traditionally shown in form of spectra, where each element energy is a peak, and the number of photons counted is the area of this peak, its common to call signal of a specific element by element peak. Silver has many peaks, some of them overlapping with other materials. It is recommended to adjust measurement and analysis to avoid overlapping peaks. The image could be done mapping silver concentration using it point by point. A concentration map could be turned into an image by transforming the number of photons counted in each point into a pixel color number, so each measurement corresponds to a pixel. The measured values can be normalized to not be greater than the maximum or smaller than the minimum, taking advantage of the entire dynamic range, or these values can still be adjusted in a window to emphasize certain details (sometimes a single pixel is much higher than all others, hiding dynamic range from the resto of the image). These previous works [7, 8] suggested mapping films by micro X-ray fluorescence (μXRF), which is, XRF with thin spot size, in order to avoid this limitation, measuring silver directly. A comparison between a radiographic film read by light transmission and directly by micro x-ray fluorescence mapping is shown in figure 3.

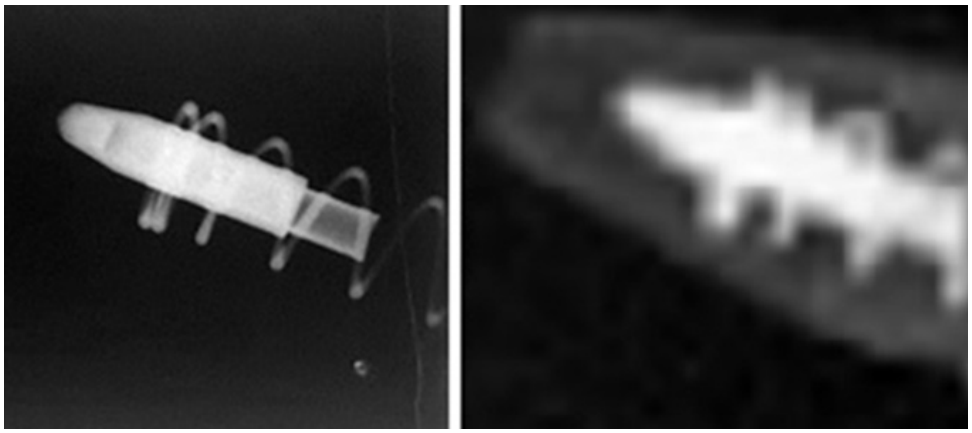

Figure 3: Radiography digitized by light measurement and by x-ray fluorescence map [7].

Despite the improvement in contrast, figure 3 shows an evident lost in spatial resolution. It is mainly due the acquisition way which was manual (and because of this, demands much time) and with a spot size of 500μm (it´s really μXRF, but demands a spot size even thinner) . A way to improve it is to acquire data in equipment build by make μXRF maps with thin spot size and setup for improve detection efficiency. There is some equipment for it, mainly for industrial proposes [10].

Another problem in digitizing by XRF map is the low exposure parts. Because of low concentration of silver, and consequently low intensity signal reaching detector, it shows a high statistical fluctuation. Contrary to what happens in indirect measurement, by light, in direct measurement there will be low signal intensity when there is little silver concentration, causing the signal to be of the order of magnitude of the noises, which means greater statistical fluctuation or even impossibility of detection.

Until now, all XRF methods was done by direct measurement of silver, counting the photons with its characteristic energy. But due the thin thickness and its flat shape of the film, the signal measured has also the contribution of the holding base of the film. For reduce this contribution, sample must be suspended, or image must be subtracted from empty holding base map.

It could be a problem, but also suggest another way to map silver concentration in radiographic film is possible: This way is based on the fact that almost all radiation beam passes through the film when an x-ray fluorescence measurement is performed. If the film is in a base with specific material, this material will also produce x-ray fluorescence. This characteristic x-ray will need to cross the film again to reach the detector, and at this moment, will be attenuated by silver concentration in each point of the film. Depending on the characteristic x-ray energy, silver could be efficient to attenuate it. When setting the detector to count the energy of this characteristic x-ray, is possible to create an indirect radiography of the own radiographic film, with discrete energy. It is like the light measurement, using the intensity of beam that reaches and crosses the film, but with many advantages.

Despite it appear to be the same way, better results is expected, mainly because of the energy selection of the photons. Even using light spectrometer, x-ray photons detectors has more accurate energy resolutions. In addition, the ambient background of light is usually bigger than x-ray photons. In this way, almost none of background photon will be counted, making the signal to noise radio with x-ray measurement far high than with light measurement.

The main objective of this work is to test this indirect measurement on silver concentration by x-ray fluorescence with different materials energy, and compare it to a direct measurement, with an industrial equipment specifically manufactured for μXRF mapping.

It was also possible, in this work rebuild the images made in previous works [7], with better spatial resolution, understanding better the limits of this method of digitization.

Materials and Methods

All materials used are from and were used in Physic Institute of State University of Rio de Janeiro, except for the light densitometer, which is from Nuclear instrumentation laboratory at COPPE, Federal University of Rio de Janeiro.

The hidden image is the part of contrast that can´t be seen by light crossing. The range limit is an instrument limitation and can be different for different setups. In this work, standard ontological patterns (used in sensitometric tests) was used do defined it. For create hidden images in films, an object like used in [7] was used, in a way to compare results. It is here called “object A” like in the previous work: a pen with metallic internal structures (an iron alloy) and a plastic cover (figure 4-A). Plastic is far more radiopaque than metals in general, and in a radiographic image, plastic structures are the first to become overexposed. The main goal is to acquire radiographic images where digitizing by light brings only metallic structures details and the plastic can´t be seen by optical density, but still there, in form of different silver concentration.

To do it, the object A has been radiographed in a way that saturates the exposure of the film, letting the plastic details in image completely blackened. These radiographies were made using a SIEMENS UNIMAX 2B dental tube (figure 4-B) and the Carestream odontological film type E (figure 4-C). Starting from

Figure 4: (A) Object A was radiographed using a Siemens x-ray tube (B) and developed by a kodak development kit (C).

the ideal radiographic image setup, the exposure time for each film was increased step by step until maximum to still having a hidden image.

Several films were made to find the best exposure setup. Then the films were developed by a KODAK development kit (figure 4-C) with the time and temperature suggested by the product instructions:

- all procedures was made at 25ºC

- at first, 3 minutes in developer

- 30 seconds washing

- 5 minutes in fixer

- final washing of 10 minutes

Drying was perform in ambient temperature with artificial ventilation.

To measure the crossing light, a densitometer X-rite 341 was used. The film with higher time exposure, in which the image of plastic structures and empty region have the same O.D but not the same XRF silver peak was chosen.

In order to acquire images from characteristic x-ray transmission through the film, with high spatial resolution and not losing efficiency in time detection, several maps were made using a High performance Micro-XRF spectrometer M4 Tornado (Flash silicon drift X-ray detector, polycapillary X-ray optics with spot size of the 25 um, rhodium target X-ray tube) from dental films on metallic bases: copper, steel and brass. Bases needed to be homogeneous and flat to not affect the results. A blank for each base was perform before putting the film on it and the resulted images were evaluated in a visual and mathematical way (by means of standard deviation of pixel number). When the film was fixed on the base, the settings still adjusted to detect the base x-ray fluorescence instead of the sample as is done normally (figure 5). Each base has its own materials. When using a steel base, iron, and chromium (which was found in steel alloy) maps were performed. When using cooper base, copper map was performed, and when using brass base, zinc and cooper maps were performed. Setup acquisition are: 50kV, step size and spot size of 25µm.

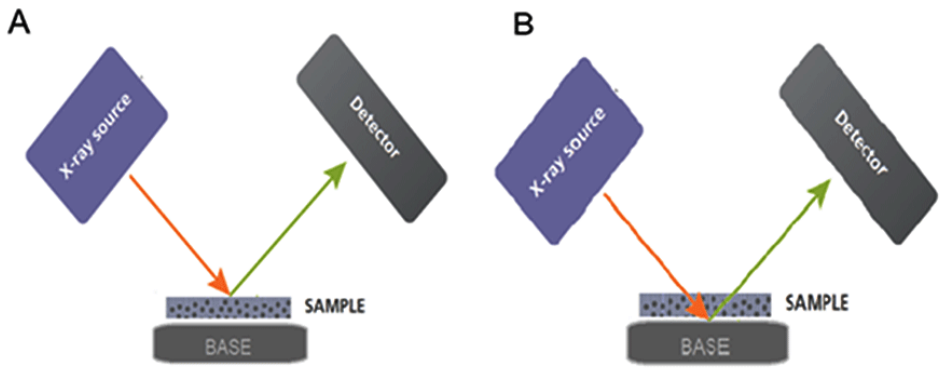

Figure 5: (A) Normal x-ray map setting (B) setting of this work.

Results

Results show images equal or even best than mapping silver directly. This methodology can be used to obtain better contrast range on radiographic films images than light measurement. First at all, it was made an image of silver peak in order to be compared with results by another energies. The standard scale set black for minimum values and white for maximum values. The intermediate values are associated to shades of gray. It´s important to say that, because of this, unexposed regions are closer to black for silver measurement and white for other elements measurement, while exposed and overexposed regions are close to white for silver and black for chromium, iron, cooper and zinc.

This resulting image has better spatial resolution than that shown in figure 6, but, has more noise.

Figure 6: Map of direct silver distribution by µXRF.

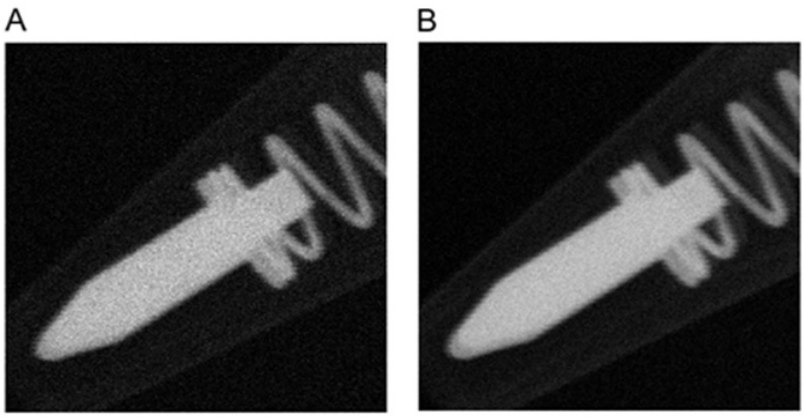

Figure 7: Digitized radiography of a film in a steel base. The images were obtained from Chrome detection (A) and iron detection (B)

Next results are from a stainless-steel base, detecting energies (Kα peak) of chrome and iron characteristic x-ray

Figure 7-A and 7-B are color inverted figure A due the nature of measurement: In direct silver values is high in black regions of the film while low in white points; but in indirect measurement, the beam reaching the detector (figure 5) is high in white parts not in the blacks. It´s also possible to see the plastic structures like in direct measurement, showing that x-ray transmission is better to measure it than light transmission.

In the follow, figure 8 shows results from a copper base, detecting cooper energy and figure 9 shows results from a brass base, detecting Zinc (A) and copper (B) energies

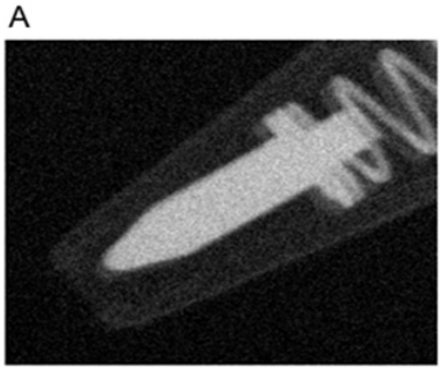

Figure 8: Radiography digitized of a film in a cooper base. The images were cooper Kα detection.

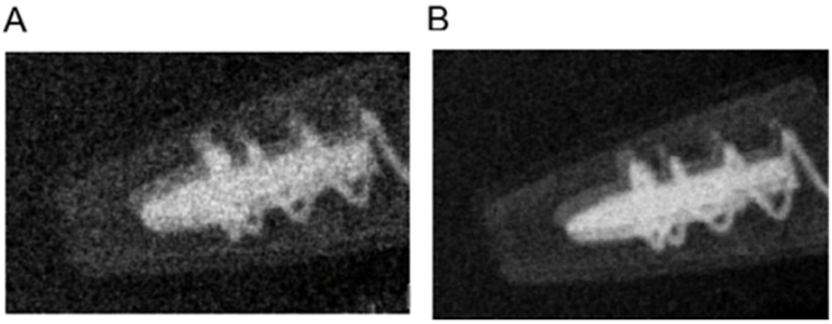

Figure 9: Radiography digitized of a film in a brass base. The images were obtained by zinc energy detection (A) and cooper energy detection (B).

Conclusions

The results show images that can´t be seen by light measurement can also be viewed by radiation transmission methods. The best images seems to be from steel bases when detecting iron.

Direct silver detection gives, for any reason, a noisier image than by radiation transmission. The process of radiation transmission can be seemed like a lowpass filter. Maybe a mathematical model can improve silver images to be like iron image.

Some energies create alias, and it´s probably because of the incident beam attenuation before hit the base. Although it damages the image, it can be used to measure some parameters such as the film thickness or the attenuation of the plastic base. Probably with the right mathematical model it can be subtracted.

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