# Corroborated X-ray imaging and elemental analysis for obtaining quantitative information from radiographs

A. CHELMUS*, R. RADVAN, L. GHERVASE
*National Institute for Research and Development in Optoelectronics-INOE 2000, Atomistilor str. no.409, Magurele city, Ilfov County, Romania*

The paper aims to present a method of obtaining quantitative information from X-rays based on the shades of grey. Relative shades of grey in radiographs are obtained due to different acquisition parameters (tube voltage, tube current and exposure time) and material type and thickness. For this method, samples made from the same material, but with different thickness, were used to create a calibration curve based on the variable grey values obtained as a result of thickness variation. To be able to create a data base for future uses, the chemical components of the sample material must be known, for this purpose a complementary elemental analysis technique, such as XRF (X-Ray Fluorescence Spectroscopy) or LIBS (Laser Induced Breakdown Spectroscopy) can be applied.

(Received December 4, 2017; accepted June 7, 2018)

*Keywords:* Grey shades, Thickness, Cultural heritage

## 1. Introduction

The use of optoelectronics in cultural heritage has increased considerably due to the development of laser techniques. These methods are non-invasive or micro-invasive, without contact or with low contact on the surface, without pressure on narrow areas. Due the fact that, in cultural heritage some, of the cultural monuments are immovable, a complex mobile laboratory was developed in our department that introduces the ability to perform in situ [1]. Most of the equipment use laser radiation, as one of the exceptions the portable X-ray radiation generator can be mentioned. Some of the equipment have teleoperation capabilities, for example Laser Induced Fluorescence LIF [2].

In some case studies, the thickness of an object, exposed to X-rays, cannot be measured without threatening its conservation state. For example when investigating an archaeological artefact, the object may be partially or entirely inside a soil bulk, as it was extracted from the site. In this case, if Computer Tomography (CT) is not an option, X-ray imaging is used to identify the presence of the object in the mass and to reveal its state of preservation, thus obtaining information about the object's approximate dimensions from radiographs that is a plus which helps the restorer. To acquire thickness information, in addition to the X-ray, a complementary method must be used to identify the elemental composition of the object. In cultural heritage, a great deal of attention is given to the non-invasive or micro- invasive character of the techniques used for investigations, so as to be the least or not at all harmful for the object. Keeping that in mind, X-ray Fluorescence Spectroscopy (XRF) or Laser Induced Breakdown Spectroscopy (LIBS) are such appropriate techniques for qualitative measurements, which can offer qualitative information on the elemental composition of an unknown object. The aim of the paper was to acquire quantitative information from calibration curves created by corroborated and post-processed data from X-ray imaging and also a qualitative elemental analysis method.

Current X-ray investigation equipment used in the field of Cultural Heritage (CH) has come a long way since 200 years ago when the first radiography of a painting was obtained [3]. Depending of the case study, radiographs can be used for qualitative information, such as the state of conservation, the differences between pigments, and the restoration interventions performed during the lifetime of a CH object. A step further would be to estimate the thickness of the object from radiographs. To this aim, databases, comprising calibrations curves for different materials or different acquisition parameters, can be developed using laboratory samples. For the X-ray investigations ISOVOLT 160 M1, a complex computerized radiography station with high-resolution digital reusable films, was used.

To be able to assign a calibration curve to a material, the exact composition of the sampled material must be known. This can be identified using a complementary technique, for example XRF or LIBS. Both techniques are highly used in cultural heritage due to their high precision measurements, portability, fast data acquisition, non-invasive or micro-invasive nature [4, 5, 6]. The choice of the elemental analysis method depends on the features of the study, for example the use of a surface analysis technique was appropriate for this particular study; when in need of more in-depth information, an alternative method, such as LIBS, can be employed.

## 2. Theory

In X-ray imaging the intra- and inter-object differences are reflected through varying shades of grey. Shades are also obtained due to different acquisition parameters – equipment dependent, material type - wood, metal, pigments, textiles, bones, glass etc., or material thickness.

The acquisition parameters, which may vary in X-ray imaging are tube voltage, tube current exposure time and distance from tube to the digital film, leading to darker or lighter shades of grey. The tube voltage is the potential difference between the two electrodes of the generator (cathode and anode), increasing the voltage, the travel speed of the electrons will be increased. Tube voltage influences the radiographic contrast, an increased tube voltage will result in a decreased contrast. The tube current affects the quantity of produced radiation, due to the power applied to the filament. Exposure time has the same effect as the tube current, changing how much is emitted by the X-ray generator.

*Table 1. Influence of acquisition parameters on the X-ray digital film*

| No. | Acquisition parameter | Increase | Decrease |
|---|---|---|---|
| 1 | Tube voltage | decrease in radiographic contrast | increase in radiographic contrast |
| 2 | Tube current | increase in radiographic contrast | decrease in radiographic contrast |
| 3 | Exposure time | increase in radiographic contrast | decrease in radiographic contrast |

X-ray beam intensity decreases at the contact with the matter, due to the interaction between the photons (radiation beam) and the atoms (matter). The attenuation depends on the atomic number and the density on the material. Materials with high atomic number (Z) produce a large attenuation and will be represented in the X-rays by light grey shades, while the materials with a low atomic number, will be more penetrable and will be visualized by darker shades. Hence for two samples of the same thickness, one made from lead-Pb (Z=82) and one from iron –Fe (Z=26), the lead sample will have a lighter grey than the iron one in the radiographs.

## 3. Results

To exemplify this method, X-ray investigations have been conducted on a set of galvanized steel samples, whose elemental composition was analysed using XRF. Sample thickness varied between 0,8 and 6,4 mm, with a 0,8 mm step. The acquisition parameters were: tube voltage 100 kV, tube current 5 mA, exposure time 30 sec, distance between tube and film 100 cm. An important aspect of this method is that the resulted calibration curve can only be used for the same material and acquisition parameters.

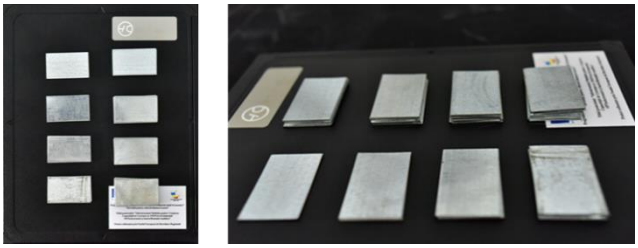

*Fig. 1. Distribution of samples on the digital reusable film*

The composition of the galvanized steel samples was confirmed using XRF, in a non-invasive, qualitative measuring method. In the obtained XRF spectra (see Fig. 2), a ratio of approximately 1/3 iron and 2/3 zinc was observed.

Samples, numbered 1 to 8 of varying thickness, ranging from 0.8 mm to a maximum of 6,4 mm (see Table 2), were exposed to X-ray investigation and their 100 kV exposure radiography is presented in Fig. 3, in which every grey rectangle represents a sample.

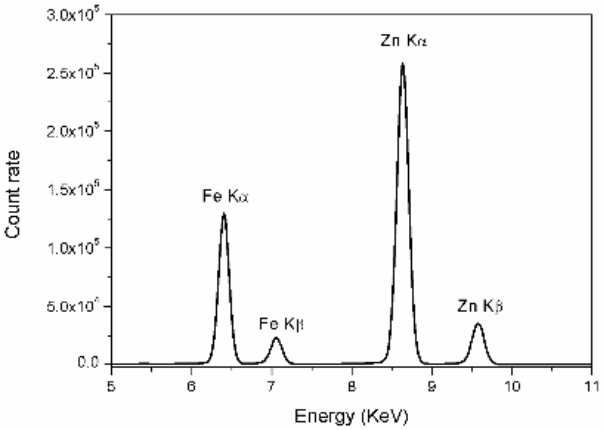


*Fig. 2. Sample spectrum from XRF investigation*

*Table 2. Samples numbered by their thickness*

| Sample number | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Thickness [mm] | 0,8 | 1,6 | 2,4 | 3,2 | 4 | 4,8 | 5,6 | 6,4 |

As it can be noticed from Fig. 3, the thinnest sample (sample no. 1) produced the darkest grey. The grey tones lighten with increasing material thickness, resulting a reverse dependence between thickness and grey shade.

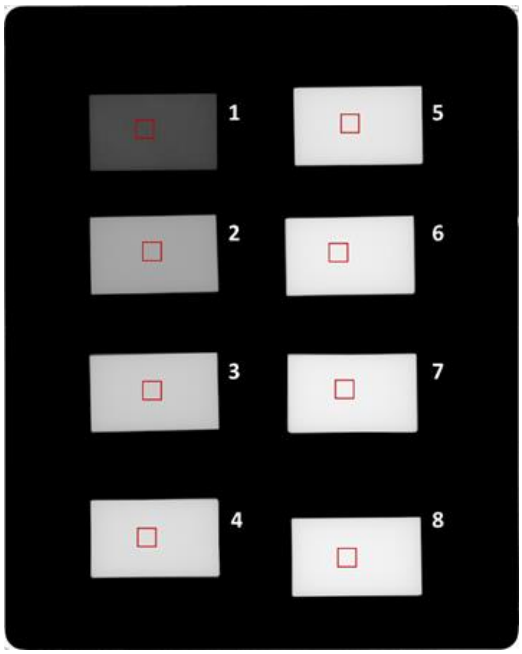


*Fig. 3. Digital radiography of the samples, obtained from 100 kV exposure*

After the X-ray exposure, the digital reusable film was scanned with a resolution of 35µm, resulting a digital image with the dimension of 5753 × 7219 pixels. The digital image must be kept in its original form, without adding any filters, so as not to change the grey tones for a better contrast [7], which can lead to thickness estimation errors. To identify different shades of grey, ImageJ specialized image analysis and data processing software (National Institutes of Health (NIH), United States) were used. Is it well known that the edge of the objects may have a slightly different grey value then the centre in radiographs, due to the halo effect, considering this aspect, the grey values were measured in a 200 x 200 pixels area selected from the centre of each sample. Using ImageJ software, the grey shades distribution and mean grey value were obtained for each analysed sample. The mean grey value is calculated from the sum of all pixels grey values divided by their number [8]. Grey scale spreads from 0 to 255, where 0 is black and 255 represents white. In radiography the darker colour means a lack of material or a complete penetration of the X-ray radiation through the material and a lighter grey represents a total attenuation of the X-ray radiation through the material. As expected, in our experiment, the lowest grey value was obtained for the sample with 0.8 mm thickness. Also, from 4 mm (sample 5) onwards, the grey values are almost 255, which means that the X radiation is almost completely attenuated, as shown in Fig. 4.

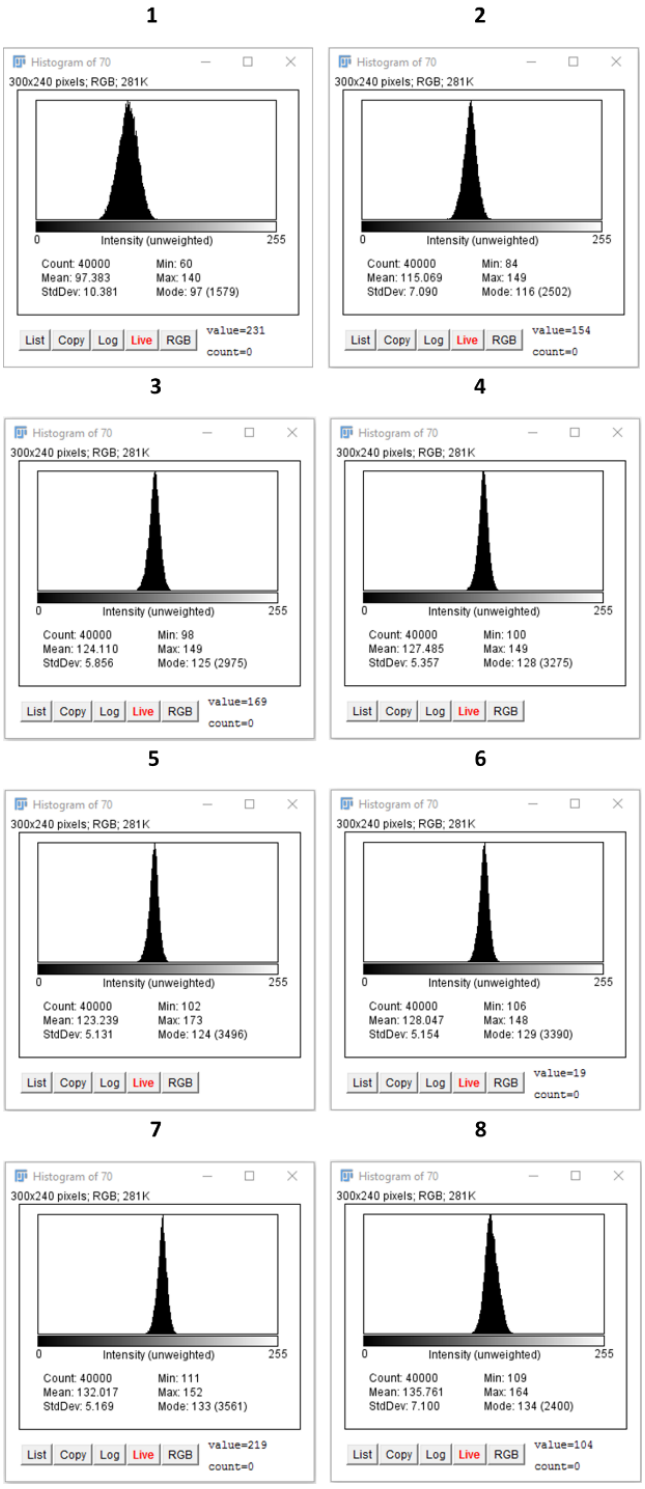


*Fig. 4. Histogram and mean value of greys for the 8 selected areas*

Using the same protocol measurements, radiographs at 70 kV, 80 kV and 90 kV tube voltage were obtained, while keeping the rest of the parameters the same. The obtained grey values are listed in Table 3 for all measuring protocols, as a function of sample thickness.

From the data presented in Table 3 a graph was plotted (Fig. 5), in which the grey value dependency on material thickness and tube tension can be observed. Analysing the variation curves, it can be noticed that starting with the thickness of approximately 4 mm, the grey values are almost at the maximum, 255, resulting that the X radiation is almost completely attenuated/absorbed by samples thicker than 4 mm.

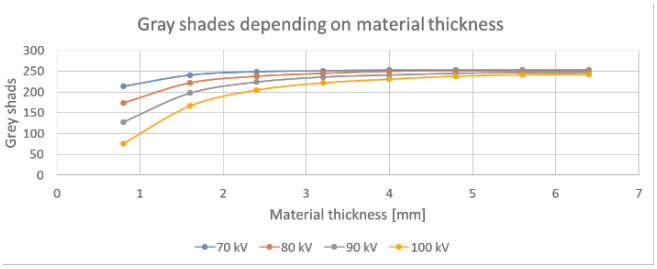


*Fig. 5. Grey shades distribution as a function of material thickness*

*Table 3. Grey values depending of material thickness and tube tension*

| No. | Material thickness [mm] | Grey shades | | | |
|---|---|---|---|---|---|
| | | 70kV | 80kV | 90kV | 100kV |
| 1 | 0,8 | 213,746 | 174,063 | 127,791 | 76,086 |
| 2 | 1,6 | 241,005 | 222,096 | 197,340 | 166,502 |
| 3 | 2,4 | 249,000 | 238,115 | 224,020 | 204,691 |
| 4 | 3,2 | 251,001 | 244,973 | 236,122 | 221,999 |
| 5 | 4 | 253,000 | 250,000 | 241,007 | 231,017 |
| 6 | 4,8 | 253,000 | 251,000 | 245,052 | 238,219 |
| 7 | 5,6 | 253,000 | 251,000 | 247,001 | 241,630 |
| 8 | 6,4 | 253,000 | 251,000 | 247,454 | 242,988 |

However, to obtain an accurate calibration curve in ImageJ, the eight values from the experiment were not enough, therefore several values were produced by interpolation (Fig. 6). The obtained curve (Fig. 7) assigns to each grey value a thickness value, so the thickness of an X-ray exposed material can be approximated automatically from the radiography based on the grey shades after applying the calibration to the radiography.

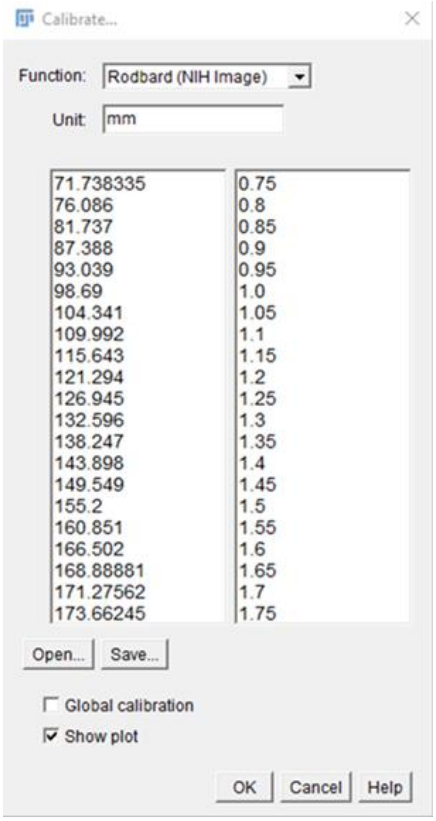


*Fig. 6 Interpolated values for grey-thickness calibration*

The calibration curve obtained from the values is approximated using the Roadbard function, which was found to be the most suitable after testing every calibration curve present in the ImageJ software.

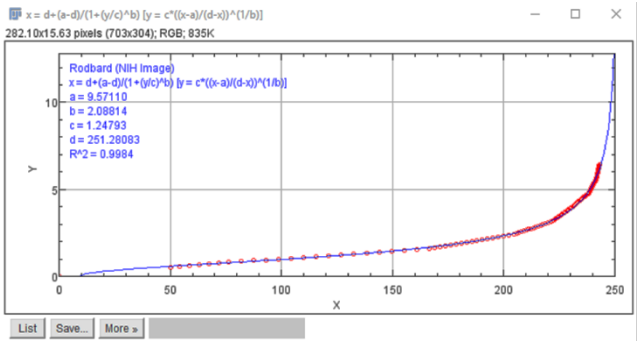


*Fig. 7. Calibration curve based on interpolated values*

Considering the fact that the calibration curve was created due to an interpolation, a difference between the known sample thickness and the one obtained, using the presented method, was to be expected. Comparing the values, a maximum difference of 0,1mm was observed. This difference may be reduced by using more calibrations points, hence more samples. The object thickness can be obtained automatically by simply selecting the interest

area. As an example, the profile of 4 samples was selected and it is shown in Fig. 8.

Following the described protocol, a further step would be to create a complex database with materials of different chemical composition, thickness and acquisition parameters. Thus, quantitative information from radiographs could be obtained, when the acquisition parameters and the chemical composition of the material are known for each calibration curve. The use of such database would be a valuable tool in the process of restoration, especially when dealing with objects formed from overlapped layers of material or materials covered with soil (such as those frequently found in archaeology).

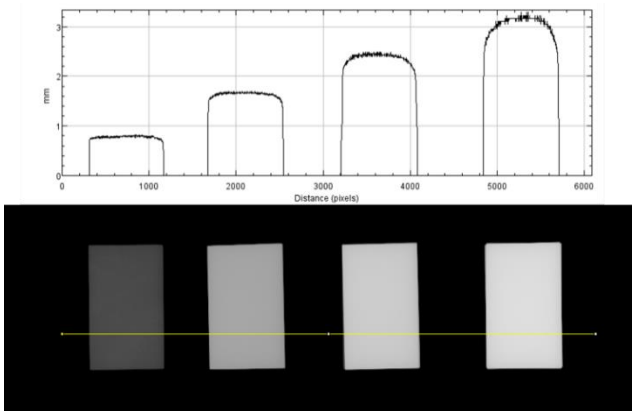


*Fig. 8. The graph represents the thickness of the profile selected in the X-ray image*

## 4. Conclusions

The paper involved a laboratory study, which aimed at obtaining the real thickness of an object from the digital X-ray images. Eight galvanized steel samples with thickness between 0.8 and 6.4 mm were used as samples. They were exposed to four different x-ray acquisition parameters from which the corresponding digital images were analysed with a specialized software. For each experimental protocol, a calibration curve was created. An additional step was the elemental analysis performed with X-ray fluorescence spectroscopy in order to establish the nature of the samples. This is an important step when investigating real samples, in order to apply the correct calibration curve. The described protocol fairly estimated the real thickness of the samples used. However, the accuracy of the calibration curves can be improved by using a greater number of samples. An additional way of improving the results could be the use of a quantitative elemental analysis method for a more refined choice of the calibration method, when several calibrations are available. Such method can be used in cultural heritage areas, such as archaeology, especially for samples showing overlapped layers of material of those buried in soil, which are not directly accessible to the specialists. An advantage of this method is that it involves the use of non-invasive equipment that does not affect the state of conservation, chromatic or chemical composition of the investigated object. The work described here will be extended by investigating materials of different chemical composition, thickness, and varying acquisition parameters.

**Acknowledgements**

This work was supported by project number 18-28 OPTRONICA V, Contract 33N/16.03.2018 and INOVA OPTIMA - POSCCE 2.2.1 - Contract 658/07.08.2014 SMIS 49164.

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*Corresponding author: alexandru.chelmus@inoe.ro