2021 International Nuclear Atlantic Conference – INAC 2021
Virtual meeting,Brazil,November 29 – December 2, 2021
ISBN: 978-65-594-1256-3

On the magnification of thermal neutron radiographs

M. I. Silvani[1], E. S. Souza[2], and G. L. Almeida[3]

[1]msouza@ien.gov.br
[2]ericasilvani@yahoo.com.br
[3]gevaldo@ien.gov.br

1. Introduction

The capability of a thermal neutron acquisition system to resolve feeble structures is ruled by its features, such as L/D ratio, geometric arrangement and detector resolution *w*. Whereas the first two parameters may be somewhat tailored, *w* is dependent upon the state of art in the field. An alternative to overcome this constraint is to magnify the radiograph. A feasible method to reach this goal through *pinhole optics* is to arrange source, object, and detector appropriately. However, a point-like neutron source is hard to simulate, especially with a low flux reactor, since the required collimation would diminish its intensity to jeopardizing thus the counting statistics. A *real* source, due to its finite size, blur the image, and hence, a trade-off must be done.

The *coded source* approach employs a mask, splitting the source into multiple small-aperture elements to preclude a large blur, while assuring a reasonable luminosity, e.g., Grunauer (1). Another magnification method, the *neutron microscope*, has been developed by Liu et al (2), but it requires a high neutron flux. To overcome the need of a high flux, Morgano et al (3) coupled an optical magnifying device to a neutron imaging system. Since these methods or devices are expensive, or require a high neutron flux, not always achievable for all facilities, a less performing, yet more affordable alternative, is the using of a *tilted* detector as done in x-ray microscopy, e.g., Shikhaliev et al (4). Goodman et al (5), reported one of the earliest works employing a tilted neutron detector - in the field of neutron time-of-flight - aiming at a trade-off between detector efficiency and time resolution. More recently, Kaestner et al (6), employed a tilted detector to perform a neutron radiograph magnification. All these works carry out a magnification along *one* direction, and the original object aspect ratio retrieved through a digital stretching along the perpendicular axis. For a low L/D ratio, nevertheless, such a straightforward technique cannot be efficiently applied, as the blur grows with the distance between the specific object region and the detector. Indeed, the higher the magnification factor, the larger that distance should be. Therefore, prior to a digital stretching to recover the original aspect ratio, that highly blurred image region must be properly *improved*.

This work proposes a technique to reach this objective by using two radiographs acquired with a tilted detector, each displaced of 180º from each other and added after a proper re-orientation. Under such a procedure, the quality of the poorer region is improved by the best one, which is concomitantly degraded by its poorer companion, but the *overall* image quality is enhanced. The resulting image is then stretched yielding the final one.

2. Methodology

The final magnified image is the sum of 2 single radiographs displaced 180º from each other which is stretched along the short axis to retrieve the primordial aspect ratio. These radiographs are acquired with a tilted detector with regard to the incoming beam. As these images exhibit different spatial resolutions at their father edges, their sum yields an overall enhanced final image. This work deals solely with *synthetic* radiographs, as its purpose is to verify the soundness of the proposed algorithm. An *ad hoc* Fortran 90 program has been written to generate the images and to process them as follows.

An example of a *virtual object* comprised of a transparent square and *opaque* strips, and the scheme to generate the synthetic radiographs are shown in Fig. 1.

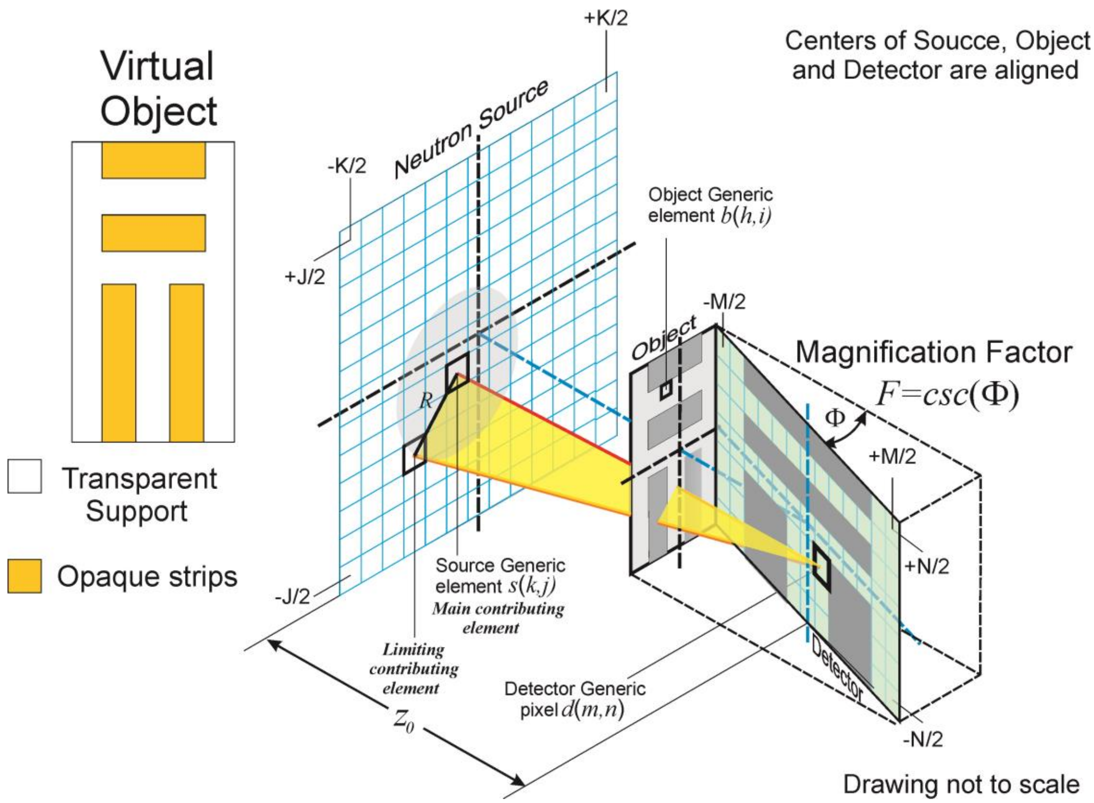

Figure 1: Virtual object comprised of a transparent square and *opaque* strips (left) and the device to acquire the radiographs (right). After the 1st exposure, the object is rotated by 180^o and the 2nd image is acquired.

With the centers of source, object, and detector are aligned, a neutron from a source elements *s(k,j)* travels perpendicularly to it until a detector pixel *d(m,n)*, where it may hit an object insert. If it does, no event is registered into this pixel, otherwise a value I_0 is assigned to it. Each insert, is characterized by its top-left and bottom-right vertices coordinates. All source elements within the circle of radius *R* - ruled by the L/D ratio - would contribute to the events registered at the pixel *d(m.n)*, and the sum of all contributions, after normalization defines its gray tonality *p(m,n)*, after the Eq. (1).

$$p(m,n)=\sum_{k=-K/2}^{+K/2}\left[\beta\left(m,n,k,j\right)\right].\sum_{j=-J/2}^{+J/2} I_0.\varepsilon.\left[z_0/z\left(m,n,k,j\right)\right] \qquad (1)$$

where:

$p(m,n)$ = Pixel value on the detector: m=-$M/2$ to +$M/2$, n=-$N/2$ to+$N/2$.

$\beta(k,l,m,n)$ = Bump function: 0 if the neutron hits an insert, 1 otherwise.

z(k,$l.m,n$) = Length of the straight line from pixel (m,n) on the detector to the source element $s(k, j)$.

I_0 = Reference intensity.

ε= Detector efficiency.

The *p(m,n)* value is ruled by the source intensity I_0, the distance z_0 to the detector, its efficiency ε, and the *L/D* ratio. The overall contribution of these parameters are condensed and normalized to the 65,535 limit of a tiff-image. The term $z_0/z(k,l,m,n)$ is a geometric factor to cope with the neutrons arriving at the detector in a non-perpendicular fashion.

In order to test the method under *real-life* conditions, the actual experimental radiograph of a chronometer, acquired with a 50 μm, has been degraded to 200 μm and the pixel intensities transformed into attenuation coefficients. With this transformation the obtained object behaves exactly like the virtual one.

3. Results and Discussion

A 4x magnified radiograph, its non-magnified companion, and photo of the bare chronometer used to produce them, is shown in Fig. 2. As seen, the first one exhibits features hardly recognizable in the non-magnified one, demonstrating thus the soundness of the proposed algorithm.

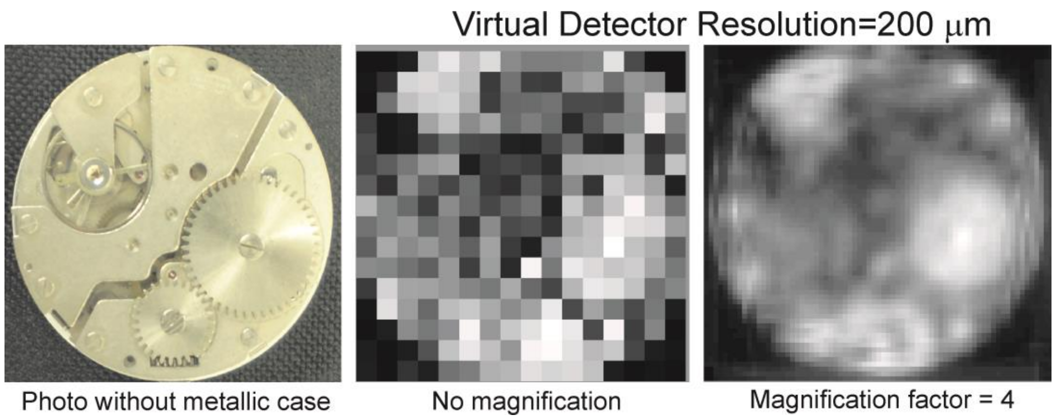

Figure 2: Bare chronometer photo (left), acquired radiograph (middle), and its 4x magnified one (right).

4. Conclusions

A methodology to magnify thermal neutron radiographs, allowing thus the recognition of feeble structures, otherwise overwhelmed by low L/D ratios and/or poor detector resolutions, has been developed, and its soundness confirmed.

References

[1] F. Grunauer, "Image deconvolution and coded masks in neutron radiography", Nucl. Inst. Meth. in Phys. Res. A542, 342-352 (2005).

[2] D. Liu, B. Khaykovich, M.V. Gubarev, J.L. Robertson, L. Crow, B.D. Ramsey, D.E. Moncton, "Demonstration of a novel focusing small- angle neutron scattering instrument equipped with axisymmetric mirrors", Nature Communications September, 1-5, (2013).

[3] M. Morgano, P. Trtik, M. Meyer, E.H. Lehmann, J. Hovind, M. Strobl, "Unlocking high spatial resolution in neutron imaging through an add-on Fibre optics taper", Optics Express 26(12), 1809-1816 (2018).

[4] P. Shikhaliev, N. Tartoni, "Improving spatial resolution in X-ray microscopy by using tilted angle detector: A simulation study", arXiv:1910.01383, [physics.ins-det] 1-20 (2019).

[5] C.D. Goodman, J. Rapaport, D.E. Bainum, M.B. Greenfield, C.A. Goulding, "High efficiency detectors for time-of-flight with highenergy neutrons", University of North Texas Libraries, UNT Digital Library, https://digital.library.unt.edu/ark:/67531/metadc1056617/ (1977).

[6] A P. Kaestner, C. Grunzweig, E.H. Lehmann, "Improved analysis techniques for new applications in neutron imaging", 18th World Conference on Nondestructive Testing, Durban, South Africa, 16-20 (2012).