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Performance Evaluation of a Micro-CT X-ray Scanner using Kanpur Theorems

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ABSTRACT:

The present work focuses on the performance evaluation of the new Micro-CT scanner installed at University of Manchester. A graphite core object has been scanned through Micro-CT scanner. The system has 2k X 2k size detector array. An experiment has been carried out with this scanner to scan the object cross section for 3796 data rays and 3600 views. The projection data obtained has been used for the reconstruction using CBP algorithm for the central plane of the object. Hamming class of filters has been used in the reconstruction. It is already shown that N_{max}, maximum gray level of the reconstructed image is a good indicator of the error in the reconstruction. This concept has been used earlier for analysis of CT images obtained from older models of X-ray CT scanners. We now use the Kanpur Theorem (KT-1) based signature for quantification of performance of this scanner. Results show very good linearity in the KT-1 graph indicating “nearly perfect” projection data and absence of any non-linear noise generated by the CT instrumentation. The second phase of current work includes application of the above work with Nano-CT machine.

Keywords: Computed Tomography, KT-1 Signature, Filter Function, CBP

INTRODUCTION

Non-destructive evaluation (NDE) using computerized Tomography (CT) is an established and popular methodology in routine inspection of various types of engineering components and materials. The advancement of technology and availability of high-resolution CT scanners makes it possible to image the cross-sections with a pixel size of μm.

Objects have been scanned using the micro-CT system installed at University of Manchester [1]. The system has 2k X 2k size detector array. An experiment has been carried out with this scanner to scan the object cross-section for 3796 data-rays and 3600 views. An attempt through experimental exercise has been made to evaluate the performance of this new scanner. The data of the central plane are processed by convolution back projection (CBP) algorithm and the resulting tomographic images are analyzed with the hamming filters.

CBP ALGORITHM

CT Scanners have been used in material NDE for the past two decades and several books provide detailed information on this particular subject [2, 3]. Details of CBP algorithm are reported by *Munshi et al.* [4]. The CBP algorithm has been described here in brief. The reconstructed function $f(r,\phi)$ is given as:

$$f(r,\varphi) = \int_{0}^{\pi} \int_{-D/2}^{D/2} p(s,\theta)\, q(s'-s)\, ds\, d\theta \qquad (1)$$

where,

$$q(s) = \int_{-R_C}^{R_C} |R|\; W(R)\, e^{i2\pi Rs}\; dR \qquad (2)$$

and

$$s' = r\cos(\theta - \varphi) \qquad (3)$$

$p(s,\theta)$ in the above equations represents the projection data, s is the perpendicular distance of the data ray from the center of the object, θ is the source position, D is the object Diameter, s'-s is the value of the data ray passing through the point (r,ϕ), R is the Fourier frequency, R_c is the Fourier cut-off frequency, $q(s)$ is the convolving function, $W(R)$ is the window function which is user dependent.

Equivalence of different family of filters has already been demonstrated in 2d cases [5] as well as 3-d cases [6]. We choose the Hamming class of filters because of their popularity in other imaging applications.

Hamming class of filters

Following, Munshi et al [7], filter function $W(R)$, with Hamming class of filters [8] is be defined as:

$$W(R) = \begin{cases} B + 2A\cos(\pi R / R_c) & |R| \le R_c \\ 0 & |R| > R_c \end{cases} \quad (4)$$

The values A and B (in the Fourier expansions) vary slowly with $1/R_c$ and

$$2A + 1 = B \qquad \text{for all values of } R_c.$$

The tomographic imaging of Graphite core, in present work is inspected by

(i) varying the shape of $W(R)$ by adjusting the parameter B and

(ii) selecting different values of R_c

Table-1 lists the four Hamming filter functions (along with their Fourier space origin second derivatives) used. R_c has been chosen according to the sampling criterion and defined as

$$R_c = \frac{1}{2(\Delta s)} \quad (5)$$

where Δs is the user selected data-ray spacing.

Code	B	Nature	$\lvert W''(0) \rvert$
h50	0.500	sharp	0.500
h54	0.540	sharp	0.460
h75	0.750	medium	0.250
h91	0.917	smooth	0.083
h99	0.999	smooth	0.001

Table 1: Details of Hamming filters selected

It has been shown [5] that the inherent error (E) at a given point (r,ϕ) in the object cross-section is given by

$$E(r,\phi) = k(W''(0))(\nabla^2 f(r,\phi)) \quad (6)$$

where,

$$W''(0) = \left. \frac{\partial^2 W(R)}{\partial R^2} \right|_{R=0}$$

and the values listed are normalized by $(\pi/R_c)^2$.

$\nabla^2 f$ in equation (6) represents the Laplacian of f and k is a constant depending on the data ray spacing. Equation (6) is valid for the objects having certain smoothness properties provided the data is perfect.

The cross-section physics (distribution) for the real objects is unknown; hence the error in the reconstruction cannot be calculated directly. This fact motivates an indirect representation of error. It has been reported earlier that for a given data set, sharpness or smoothness can be used as an indicator of the error behaviour, arising due to choice of the filter function. The sharpness parameter corresponds to N_{max}, the maximum grey level (linear absorption coefficient) in the reconstruction [9, 10, 11].

DATA COLLECTION

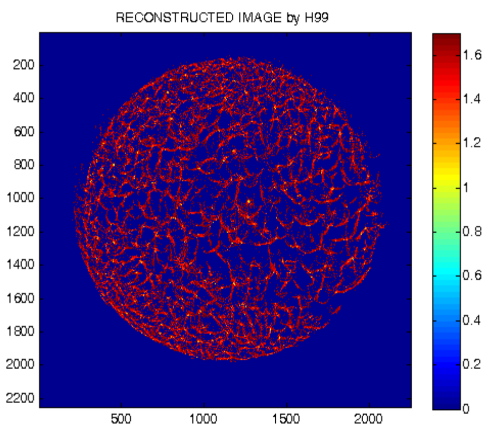
The test object selected for this study is graphite core. Data is taken in the form of parallel-beam geometry and detectors used are of 2k X 2k size. Data is collected for 3600 projection views. The data is stored as an array of 16 bit integer. The slice is flat field corrected i.e. ring artifacts and high peaks are removed. The object center is not on the source detector line. The image center is at 1736. A software correction has been applied to remove the off-centered artifacts. The data obtained after the correction is raw data. We have to invert it and then multiply it with the maximum value in the data set before taking the logarithm.

RESULTS & DISCUSSION

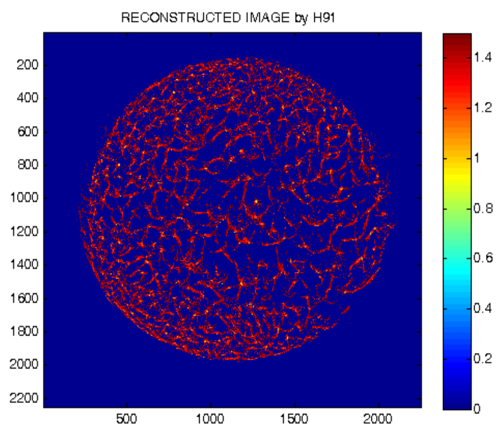
The test object selected was scanned from micro-CT scanner installed at university of Manchester for 3796 data rays and 3600 projection views. The image is displayed on a 2250 × 2250 matrix of 256 gray levels. The pixel size is in µm.

Reconstruction with experimental data

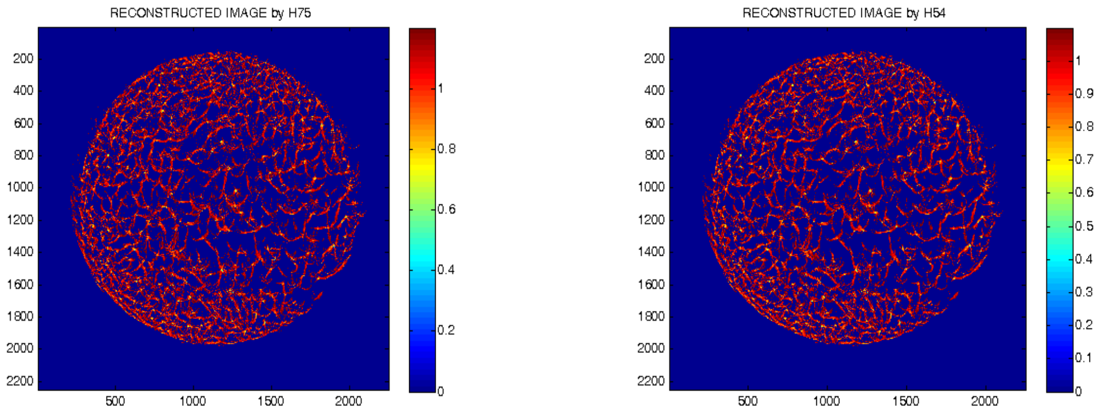
Simplified experimental parallel-beam data is processed through Convolution Back Projection (CBP) algorithm, developed at Tomography Lab, Indian Institute of Technology Kanpur. Reconstruction of this test object has been made for four Hamming class of filters. Figure 1 shows the reconstructed cross-section of the test object for 3796 data rays and also images for four Hamming classes of filters with symbols (a)–(d). It is observed that reconstruction is better with sharp filters. Figure 2 shows the fidelity of the projection data as per the first Kanpur theorem.



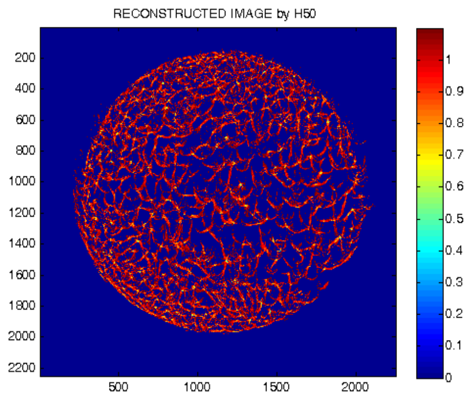
(a)



(b)



(c) (d)



(e)

Fig. 1: Reconstructed image with (a) h99 (b) h91 (c) h75 (d) h54 (e) h50 Hamming class Filters

Analysis

Errors can be analyzed either through N_{max} (sharpness parameter) or $1/N_{max}$ (smoothness parameter) of each data ray for different Hamming filters. The present work uses $1/N_{max}$ (smoothness parameter) i.e. an indicator of error for analyses. Error for reconstructed image with different filters is indicated in Table-2. These values are also plotted in Fig.2.

Fig. 2 shows a linear behavior for 1/Nmax against W''(0). The departure from the linearity can be contributed to the noise in the experimental data. It shows that the data collected from the experimental system is good and no non-linearity appearing in the experimental data.

S. No.	Filter Function	W’’(0)	Nmax	1/Nmax
01	h99	0.001	1.2957	0.7718
01	h91	0.083	1.2509	0.7994
02	h75	0.25	1.1632	0.8597
03	h54	0.46	1.0753	0.9300
04	h50	0.50	1.0561	0.9469

Table 2: Error values for reconstructed image with different filters

S. No.	Slope	Intercept	Norm of Residuals
01	0.34899	0.77124	0.0025834

Table 2: slope, intercept for KT-1 plot

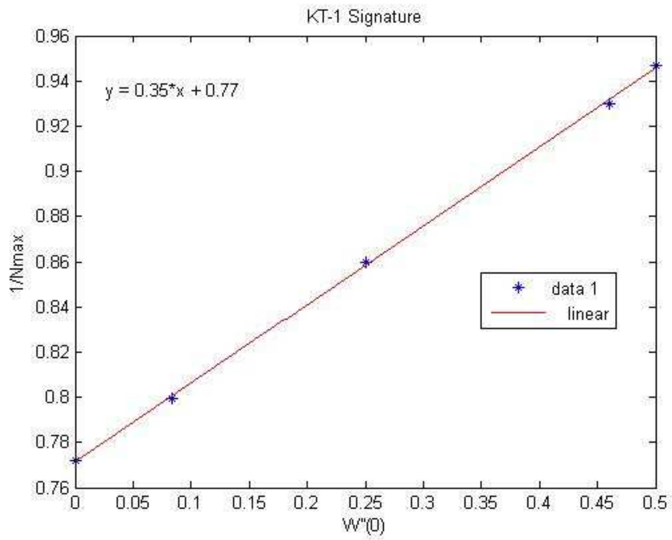


Fig. 2: KT-1 Signature for the experimental data

CONCLUSIONS

This work is the first experimental check (involving KT-1 signature) of the new micro-CT system of the University of Manchester. The results for the central plane indicate that projection data is very good as per guidelines of the KT-1 concept.

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