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ORIGINAL ARTICLE

Image reconstruction technique using projection data from neutron tomography system

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Abstract Neutron tomography is a very powerful technique for nondestructive evaluation of heavy industrial components as well as for soft hydrogenous materials enclosed in heavy metals which are usually difficult to image using X-rays. Due to the properties of the image acquisition system, the projection images are distorted by several artifacts, and these reduce the quality of the reconstruction. In order to eliminate these harmful effects the projection images should be corrected before reconstruction. This paper gives a description of a filter back projection (FBP) technique, which is used for reconstruction of projected data obtained from transmission measurements by neutron tomography system We demonstrated the use of spatial Discrete Fourier Transform (DFT) and the 2D Inverse DFT in the formulation of the method, and outlined the theory of reconstruction of a 2D neutron image from a sequence of 1D projections taken at different angles between 0 and π in MATLAB environment. Projections are generated by applying the Radon transform to the original image at different angles.

1. Introduction

Neutron tomography (NT) is a powerful technique for three-dimensional visualization of hydrogenous substances such as rubber, water, oil, explosives, and wood even wrapped by thick metal layers. The experimental and safety conditions in different neutron sources such as nuclear reactors, spallation sources and standard particle accelerators make, in most cases, the facilities very different from each other. This implies that neutron tomography can yield information in cases where other NDT techniques fail. Neutron tomography already proved to be useful in many different areas such as archaeology, geology, biology, sciences, cultural heritages and industrial applications [1–3]. Fig. 1 shows the mass attenuation coefficients for thermal neutrons and 100 keV X-rays for the elements.

A neutron image is obtained by irradiating the object in an uniform neutron beam and recording the intensity transmitted by the object. Several solutions have been used for image recording: X-ray films and track-etch foils associated with converter screens (gadolinium, dysprosium and boron), neutron scintillators coupled to Charge Coupled Devices (CCD) video

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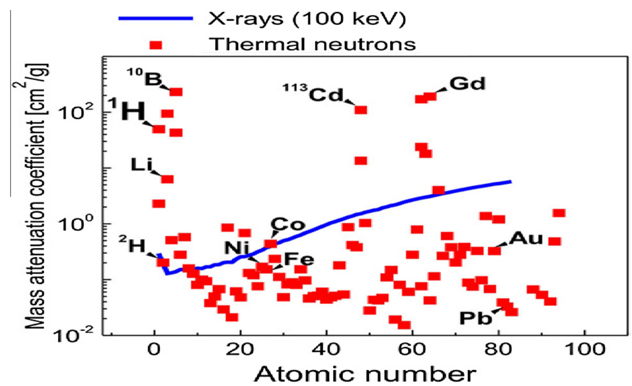

Figure 1 Mass attenuation coefficients for thermal neutrons and 100 keV X-rays for the elements (natural isotopical mixture unless stated differently) [2].

cameras and neutron imaging plates. The Neutron computed tomography can be used to obtain important 3-D information about the object's internal structure and material properties that other traditional methods cannot provide. Typically, a neutron computed tomography system consists of a neutron source with a collimator, a sample rotation device, a 2-D neutron imaging system and a motion control system which synchronizes sample rotation with the imaging system. A computer to capture, store and reconstruct the 3-D images is also needed. The first step in the development of a neutron tomography system is to select and optimize the neutron imaging and the second step is the preparation of the image data and subsequent calculation of the 3-D voxel array using one of many reconstruction techniques, such as a filtered back-projection or an algebraic reconstruction algorithm [4]. Tomography image visualization software that recombines the 2-D vertical images into a 3-D image is commercially available and is useful to analyze the 2-D image projections [5]. Fig. 2 shows the principle of computed tomography system.

ETRR-2 is an open pool type Material Testing Reactor (MTR) of 22 MW thermal power. The reactor is cooled and moderated by light water and reached first criticality in 1997. Irradiation facilities and beam tubes are installed at the reactor for research purposes as shown in Fig. 3. Neutron radiography facility is one of these beam tubes and was commissioned in 1999 using static based film neutron radiography [6].

The neutron radiography facility at ETRR-2 is upgrading from static based film (Nitrocellulose film and Agfa Structurix D7 photographic film) neutron radiography system into dynamic system neutron radiography/tomography by using Scintillation screens (ZnS (Ag)–6LiF) and a CCD-camera, and instrument was commissioned in January 2013.

2. Basic concepts

The image reconstruction techniques use the measured projection data as input to calculate the density distribution of the desired cross section of the investigated sample as output. Accordingly, the two dimensional image of the desired cross section can be obtained. The applicable reconstruction techniques are divided into three categories: first back-projection reconstruction, second by iterative reconstruction, and third by analytical reconstruction. The Filtered Back Projection (FBP) technique is used in most commercial medical scanners and has proved to be extremely accurate and amenable to fast implementation. This technique can be given a rather straightforward intuitive rationale because each projection represents a nearly independent measurement of the object. A brief discussion of the FBP is given below.

2.1. Projections

The Filtered Back Projection algorithm uses Fourier theory to arrive at a closed form solution to the problem of finding the linear attenuation coefficient at various points in the cross-section of an object. A fundamental result linking Fourier transforms to cross-sectional images of an object is the Fourier Slice Theorem [7–9].

Let x, y represent the coordinates inside the object (Fig. 4), and $f(x, y)$ the density (attenuation coefficient) in rectangular coordinates of the object under consideration at the cross-section at which the imaging has to be done. Let Eq. (2.1) represent the projection of the object at distance, t, from the center. The equation of the line AB is $= x$ cos(theta) + y sin(theta), where we use "theta" (rotation angle) in place of the Greek symbol. Then, the projections are defined as [7]:

$$P_\theta(t) = \int_{(\theta,t)line} f(x,y)ds \tag{2.1}$$

It has been shown [3] that the above equation can be written using a delta function as:

$$P_\theta(t) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} f(x,y)[\partial(x\cos(\theta) + y\sin(\theta) - t)dxdy] \tag{2.2}$$

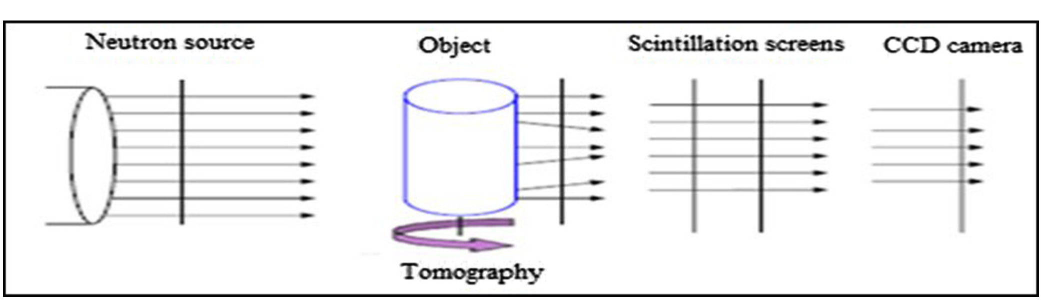

Figure 2 Principle of computed tomography.