Available online at www.sciencedirect.com

ScienceDirect

Physics Procedia 88 (2017) 340 – 347

Physics Procedia

8th International Topical Meeting on Neutron Radiography, Beijing, China, 4-8 September 2016

# Study of signal to noise ratio of coded source neutron imaging with analysis method and numerical simulation

Sheng Wang[a,b], Hang Li[a,b], Chao Cao[a,b], Yang Wu[a,b], Heyong Huo[a,b,*], Bin Tang[a,b],
Yubin Zou[c], Yuanrong Lu[c], Guoyou Tang[c], Zhiyu Guo[c]

[a] *Institute of Nuclear Physics and Chemistry, CAEP, Mianyang, Sichuan 621900, China*
[b] *Neutron Physics Laboratory, CAEP, Mianyang, Sichuan 621900, China*
[c] *State Key Laboratory of Nuclear Physics and Technology &School of Physics, Peking University, Beijing 100871, China*

## Abstract

Coded source imaging (CSI) technique could increase the utilization rate of neutron when high L/D required in neutron imaging. The images need to be reconstructed from the raw projections. The reconstruction would amplify the noise of the raw projection, which will affect the quality of reconstructed images. Study of Signal to Noise Ratio (SNR) in CSI shows image quality depends on geometry structure and neutron beam parameters. With analysis method based on correlation reconstruction arithmetic, SNR was detailed to assess the effects from different geometry factors. Numerical simulation as a further supplement proves the rationality of analysis method. The comparison of SNR between CSI and traditional neutron radiography (NR) shows that the SNR of CSI could be better than NR in some conditions.

*Keywords:* Coded Source Imaging; Neutron Imaging; Signal to Noise Ratio; Reconstruction Method

## 1. Introduction

Neutron imaging with CSI technique can increase the utilization ratio of neutron at a high L/D condition. So it is benefit to phase contrast neutron imaging and other fields which need high L/D. Antonio et al. (2006 and 2007)

---

* Corresponding authors: Tel.:+86-0816-249-4238.
*E-mail address*: huoheyong@163.com.

doi:10.1016/j.phpro.2017.06.046

studied the possibility to carry out phase contrast neutron imaging using CSI at MIT Reactor. Simulations of coded source neutron imaging were carried out with different reconstruction algorithms by Grünauer (2005), Xiao et al. (2009), Li et al. (2011), Wang et al. (2011), Bingham et al. (2011) and Santos-Villalobos et al. (2012 and 2013). Some neutron experiments of CSI were carried out based on reactors too. Grünauer (2006) achieved the reconstructed images with a NRA coded source at ANTARES of FRM-II. A MURA coded source neutron imaging was tested at ANTARES by Zou et al. (2011). Xiao et al. (2011) took neutron experiments of CSI at PULSTAR reactor. Bingham et al. (2014) developed a CSI system at High Flux Isotope Reactor (HFIR) CG-1D instrument to improve resolution of neutron radiography. In recent years, preliminary neutron experiments were carried out at PKU Neutron Imaging Facility (PKUNIFTY) based on an RFQ accelerator by Wang et al. (2013) and Zou et al. (2011). The compare of neutron radiography and coded source imaging has been described in Wang el al. (2015), and three reconstructed methods were given in that paper too.

In CSI, sample images need to be reconstructed from the raw projections, which is a fold-over of sample distribution and codec. The reconstruction process may amplify the noise of the raw projection, which would reduce image quality of reconstructed images. Study on SNR of reconstructed images in CSI is helpful to evaluate the practicability of CSI. Reasons affecting SNR have been detailedly studied in coded aperture imaging (CAI) Fenimore (1978) and Accorsi (2001). With the similar structure, it is easy to get analytical expression of SNR in CSI, which is based on correlation reconstruction method.

This paper gives the analytical expression of SNR in coded source neutron imaging with geometry structure and neutron beam parameters. The expression shows that SNR of coded source neutron imaging is mainly related to the neutron beam flux, the exposure time, the mask arrangement, the object distribution and the background noise. Numerical simulation is used to confirm the rationality of analysis method. The analytical method is only depended on correlation reconstruction method, but numerical simulation could calculate SNR value with correlation reconstruction method, Wiener-filter deconvolution method and maximum likelihood iteration method. With numerical simulation, we could compare CSI with NR too. The results show that SNR of CSI is better than NR under the same L/D ratio in certain geometry structure and neutron beam arguments, which is corresponded with the results of the analytical method.

As a novel neutron imaging method, code source neutron imaging couldn't displace NR totally. In further work, more neutron experiments will be carried out at INPC and PKUNIFTY.

## 2. Analysis Method

### 2.1. SNR of NR

The flux at the imaging plane and the distance between neutron source and samples determine the signal accumulation rate of each detector pixel. The SNR of CSI with neutron beam arguments needs to consider Gaussian noise in each detector pixel. Firstly, we will give the SNR expression of NR with neutron arguments.

Neutrons from the source penetrate the sample and reach the detector. Ignoring sample absorbing, the neutron intensity (neutron amount per unit time) $I_p$ at each detector pixel in projection could be expressed as Eq. (1). The sketch map is shown in Fig. 1.

$$I_P = \frac{I_0 S_0}{4\pi Z^2}\cos^3(\theta) S_d \tag{1}$$

Where $I_0$ is the neutron flux at the neutron source position, $Z$ is the distance between neutron source and the detector plane, $S_0$ and $S_d$ is the area of neutron source and each pixel of projection. $\theta$ is the angle between the neutron path and the normal direction of detector plane.

Considering an actual distribution of the sample, we could get the SNR of total projection as Eq. (2), and single pixel of $(x,y)$ in the projection as Eq. (3) at Fenimore (1978). The background intensity is assumed to be even.

Eq. (2) shows that the effective signal is average brightness of ideal sample image, and imaging noise is standard brightness deviation between exposed projection image and ideal sample image. Eq. (3) shows the effective