A Sequential Coded Apertures Imaging System

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ABSTRACT

To measure the intensity distribution of the n/g radiation emitted from the target of the Intense Resonance Neutron Source (IREN), a new n/g imaging system is proposed. The spatial resolution of an imaging system is usually limited by that of the position n/g-sensitive detector. In this work, we present a new imaging method, which takes advantages of a sequence of coded apertures. With this method, the number of pixels in the position-sensitive detector we needed can be significantly reduced. The simulations for thermal neutrons show that, when the number of detecting pixels is limited, these sequential coded apertures lead to a higher signal-to-noise ratio (SNR), than the widely used modified uniformly redundant array (MURA).

1. INTRODUCTION

At the moment the IREN facility is in stage of testing and modification. The current intensity of the neutron radiation from the neutron producing target (NPT) is ~10^{11} n/s. To control the n/g- production process, we are going to visualize the NPT using n/g imaging system. Because the neutron yield is not very high, the coded aperture imaging technique may be suitable for this task.

The coded aperture imaging [1] consists of two steps: encoding process and image reconstruction. In the first step, a coded aperture is placed between the neutron source and a position-sensitive detector. The coded aperture could be a pinhole array, penumbral aperture, ring aperture, and so forth. In the second step, the source's n/g-radiation distribution is reconstructed from the coded image with the knowledge of the aperture used. If a suitable aperture and reconstruction method are employed, it is possible to recover the source's n/g-radiation distribution with a high resolution and an improved statistical quality.

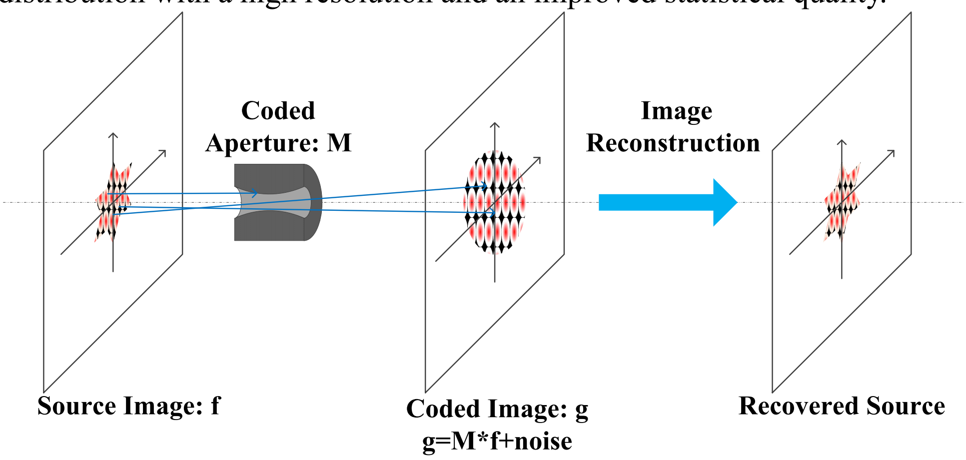

Fig. 1. Two steps of the coded aperture imaging.

2. THE IMAGING SYSTEM

We are going to use an 8×8 Si-stripe pad as a position-sensitive thermal neutron (n_{th}) detector. The number of the “effective pixels” of this detector is 64, and each pixel’s size is 1.5 x 1.5 cm. To detect the thermal neutrons, a n_{th}-converter is needed. Two materials are considered: ^6LiF and B_4C. The Boron consists of 80% ^{10}B and 20% ^{11}B. Monte Carlo simulations (Geant4) shows that the detection efficiency of ^6LiF (optimal thickness = 25 mm) is much larger than that of B_4C (optimal thickness = 1 mm). Thus, a ^6LiF converter is adopted in the following analysis.

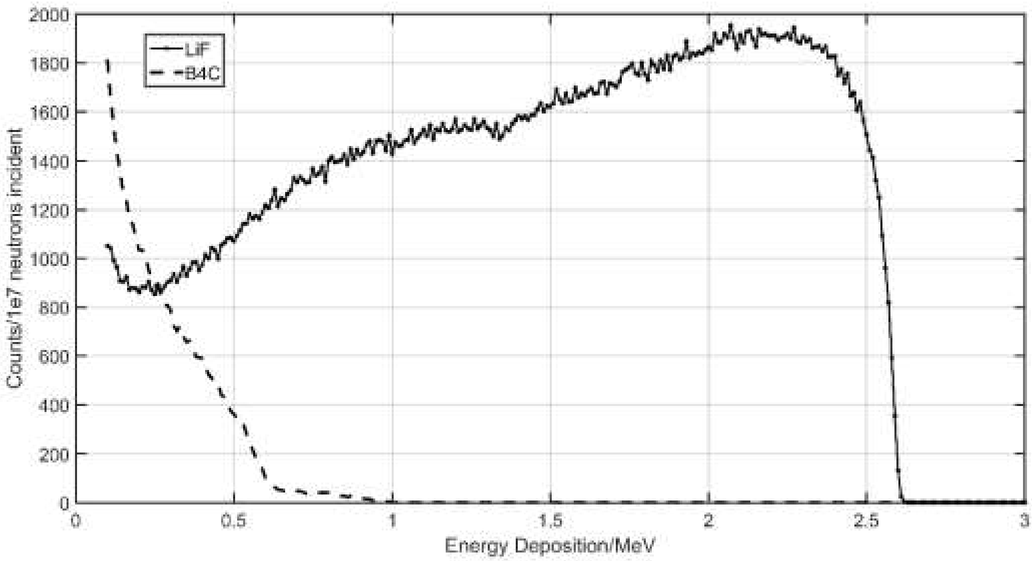

Fig. 2. Energy depositions in silicon.

Because the number of Si-pixels is rather small, two schemes are designed to overcome this problem. In scheme I (Fig. 3), the Si-detector is removable. After a measurement is finished, the detector is moved to another position for the next measurement. In this way, we can record 64×64 pixel coded images.

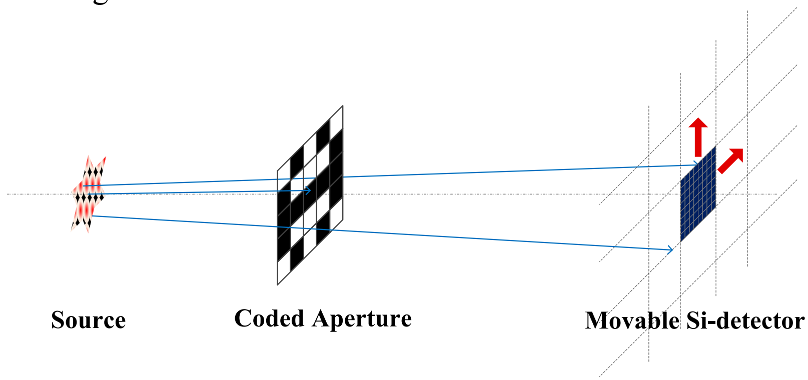

Fig. 3. Scheme I: moving the detector.

In scheme II (Fig. 4), the detector is fixed, but the pattern of the coded aperture is different in each measurement. The coded aperture consists of two groups of orthogonal strips, similar to the Pseudo-Noise Product (PNP) coded aperture array [2], except that the pattern is not invariable during imaging. Before each measurement, the strips are randomly rearranged - insert or pull out some strips. This idea comes from the single pixel camera [3] in *compressed sensing*. In this way, the source image is sampled in a compressed form, thus the number of detecting pixels required can be significantly reduced.

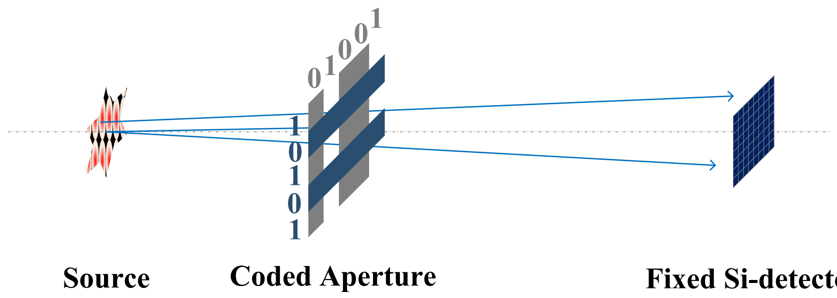

Fig. 4. Scheme II: changing the aperture's pattern.

3. SIMULATION RESULTS AND DISCUSSION

To compare these two schemes, we have carried out some simulation calculations for thermal neutrons. The coded aperture used in scheme I is a 61 × 61 MURA coded pinhole array [4] (basic patterns: 31× 31), the size of each element is 7.5 × 7.5 mm. In scheme II there are 24 strips in horizontal and 24 in vertical positions. The material of aperture is cadmium (Cd) with a thickness of 0.5 mm. The other parameters are: total thermal neutron yield (in 4π) = 10^{12}, field-of-view in the source's plane FOV = 20 × 20 cm^2; source-to-aperture distance = 1.5 m; source-to-detector distance = 6.0 m. The image recover method used in this work is a L1-minimization algorithm [5].

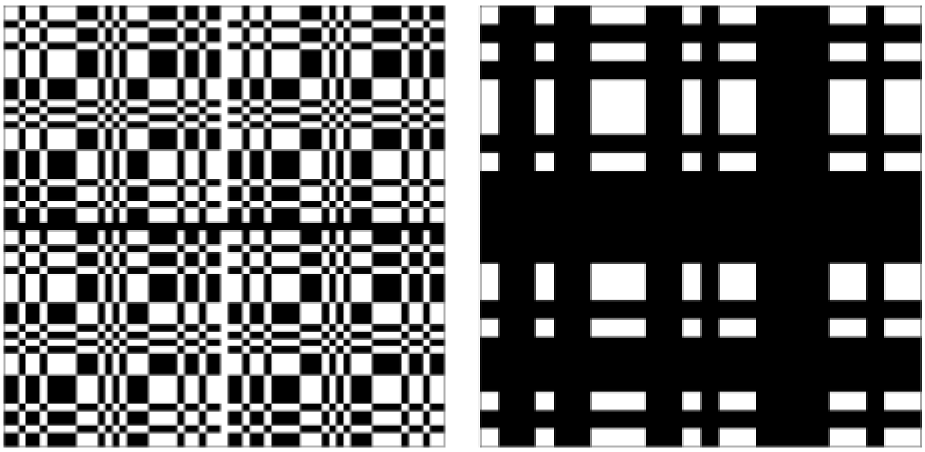
Fig. 5. Coded apertures used in this work.
Left: the MURA. Right: one of the sequential coded apertures.

Note that in scheme I we should take 64 measurements to record the whole coded image. Thus, in scheme II we also take 64 measurements to make a fair comparison. The neutron yield in each measurement is $10^{12}/64$. With the same neutron yield and number of measurements, the scheme II could lead to a higher SNR (with source image as the reference) and sharper edges, as shown below in Fig. 6.

To study the relationship between the SNR of the recovered source and the number of measurements, we adjusted the latter in scheme II. The neutron yield is each measurement is $10^{12}/64$. The results are shown in Fig. 7. At first, the SNR of the recovered image increases fast with increasing the number of measurements. With more than 20 measurements the SNR of this scheme will exceed that of scheme I with 64 measurements.

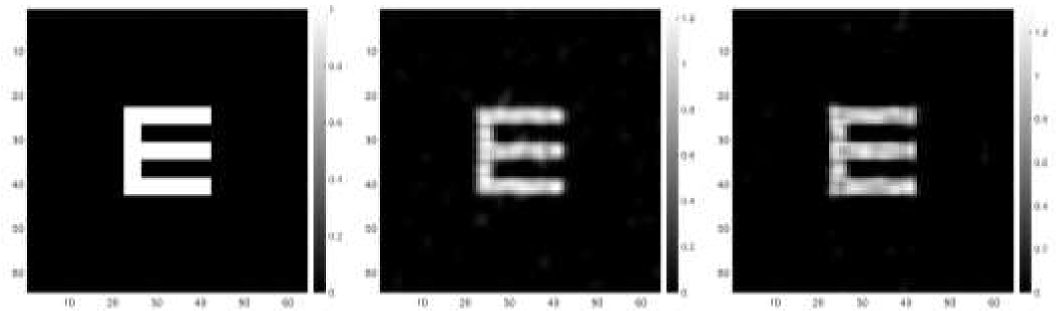

Fig. 6. Simulated reconstruction images. Left: the source image. Middle: by Scheme I, SNR=11.9 dB. Right: by Scheme II, SNR=15.1dB.

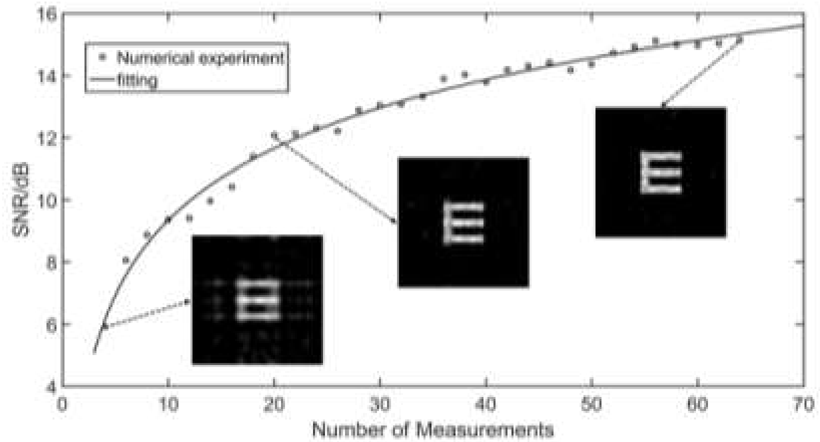

Fig. 7. The SNR of recovered source vs. number of the measurements.

4. CONCLUSIONS

In this work we present a sequential coded apertures imaging system for a radiation source that can be measured repeatedly. The simulated thermal neutron image reconstruction shows that, with a limited number of detecting elements (sensor pixels), this method could also lead to high fidelity source distribution within dozens of measurements. This method can also be used in gamma imaging. In that case, the position resolution and energy resolution can be achieved simultaneously.

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