jnm/ PRELIMINARY NOTE

A METHOD OF TOMOGRAPHIC IMAGING USING A MULTIPLE PINHOLE-CODED APERTURE

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A method of obtaining tomographic images from a single exposure to the gamma rays emitted by an object is described. The method uses an aperture of multiple pinholes to produce a coded shadowgram on a large-area detector. The resultant pattern must be decoded with a diffuse white light source and the original aperture to produce the image.

The simplest method for imaging a gamma-emitting object is to interpose a single pinhole between the object and the recording detector. The gammas that originate from the object and pass through the pinhole produce a recognizable image of the object on the detector with a lateral spatial resolution dependent upon the pinhole size. Decreasing the size of the pinhole increases the spatial resolution of the system but reduces the detection rate of the gammas that are recorded. Thus, exposure times are prolonged. Adding more pinholes increases the data-taking rate but now the pinhole images produced on the detector overlap one another and are spread over a larger area of the detector. The object is no longer recognizable and a means of decoding the resulting shadowgram is required.

The multiple pinhole array described here has the property that the vector distance between any two pinholes occurs only once, i.e., the pinholes are spaced nonredundantly. Several examples are described in the literature (*1–3*). This characteristic of nonredundancy means that the autocorrelation of the pinhole array function is peaked at the center and is uniformly flat elsewhere. Thus, if parallel light is directed toward two similar nonredundant pinhole arrays placed along the same axis, the light will pass through all the pinholes in both arrays if the arrays are completely aligned but only through a pair of them, on the average, if the arrays are not aligned.

Wouters, et al (*4*) have shown with optical simulations that if the original pinhole array is used to decode the shadowgram, the peaked shape of the autocorrelation produces an image of the object on a uniform background of light. We demonstrate that for gamma-ray imaging, a faithful reconstruction of the object can be made in this way with a minimum of defects and artifacts produced. Furthermore, because the pinhole aperture subtends a finite angle at the object, tomographic effects are obtained.

MATERIALS AND METHODS

Figure 1A is a diagram of the imaging system. An actual coded shadowgram from a thyroid phantom is shown. It was photographically recorded from the face of the CRT on 4 × 5-in. film. The primary radiation detector that we used was a gas-filled multiwire proportional chamber with delay-line readout (*5,6*). We chose this detector because it is capable of detecting efficiently single-gamma interactions with good spatial resolution (~1 mm), and produces coordinate information that is easily displayed on a cathode ray tube or digitized for computer processing. In addition, the detector is conveniently made with large-detection areas of the order of 30–50 cm on a side. The resolution is necessary if the smallest details of the object are to be clearly imaged. The large area is necessary in order to record all of the overlapping images of the coded shadowgram. Thus, the pinhole diameters can be made correspondingly smaller to match the detector response and the object resolution desired whereas the detector area is still large enough to record the entire field of view of the coded aperture.

The lateral spatial resolution is similar to that for

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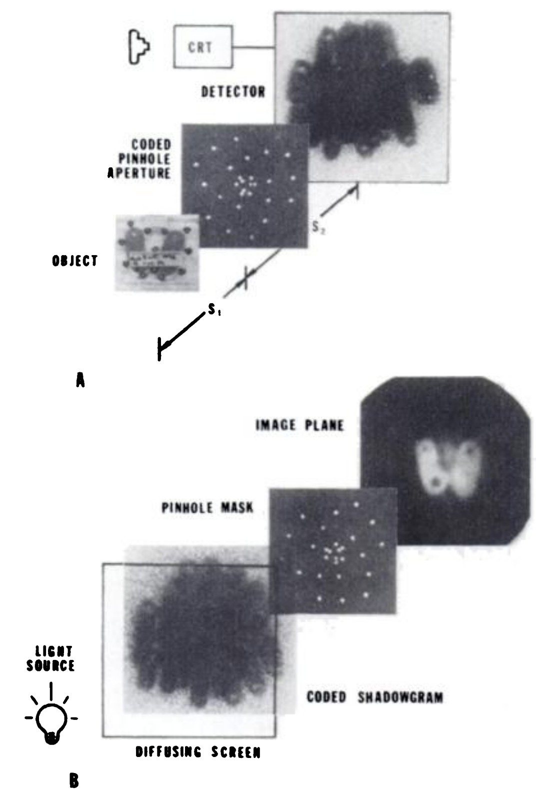

FIG. 1. (A) Composite diagram of imaging system shows spatial placement of various components depicting 27 nonredundant pinhole array and actual shadowgram of Picker thyroid phantom. (B) Composite diagram of reconstruction system shows decoded image of shadowgram.

a single pinhole, and is given by $\delta = d(1 + S_1/S_2)$ where d is the diameter of the pinhole and S_1 and S_2 are as shown in Fig. 1A. The depth resolution is given by $\Delta = 2(d/D)\ S_1(1 + S_1/S_2)$ where D is the largest lateral distance between any two pinholes of the array. This calculation for the depth resolution assumes that 50% of the light from the out-of-focus planes overlaps the light from the in-focus plane.

The coded aperture consists of 27 2-mm-diam pinholes drilled into a flat sheet of lead 2 mm thick and was designed to work with gammas up to 140-keV energy. In this application, the radiation was the 28-keV x-rays emitted by a ^{125}I-filled thyroid phantom. The resolution of the system is limited by the 2-mm-diam size of the individual pinholes and, thus, for a typical imaging geometry in which $S_1 = S_2$, the overall lateral resolution is 4 mm.

The reconstruction system is shown in Fig. 1B. An intense, uniform, and diffuse light source is made by focusing the light from a slide projector onto a ground-glass screen. The rays of light emitted from the screen are further transmitted through the transparency of the shadowgram and through a mask that is a duplicate of the original nonredundant pinhole array. When the shadowgram and mask are properly aligned, the decoded image comes into sharp focus at an image plane where it can be directly observed on a second ground-glass screen and subsequently photographically recorded.

RESULTS AND DISCUSSION

An image of a Picker thyroid phantom taken with the 27 nonredundant pinhole-coded aperture is shown in Fig. 1A. The shadowgram consisting of 540,000 dots was recorded on Kodak Ektapan film. The reconstructed image as shown in Fig. 1B was printed on high-contrast paper to reduce the background of light and enhance the contrast. The right and left lobes differed in activity and this difference can be seen in the reconstruction. The smallest of the cold nodules is 5 mm in diameter and is clearly imaged.

The tomographic capability of this coded aperture is shown in Fig. 2. Figure 2A shows the shadowgram of a radioactive phantom consisting of three geometric patterns labeled with ^{125}I (a cross, a triangle, and a circle) which were separated by a distance of 2.5 cm in depth. A total of 1 million gammas was recorded on the shadowgram. Figures 2B, C, and D are the reconstructions of each of the patterns obtained by adjusting the mask-to-image plane distance in the reconstructions so as to bring each pattern into sharp focus. Each of the in-focus images is superimposed on a background arising from the planes at other depths in the phantom. Since no movement of the detector is necessary and all the information of the shape and size of the object is recorded in a single picture, dynamic studies are possible.

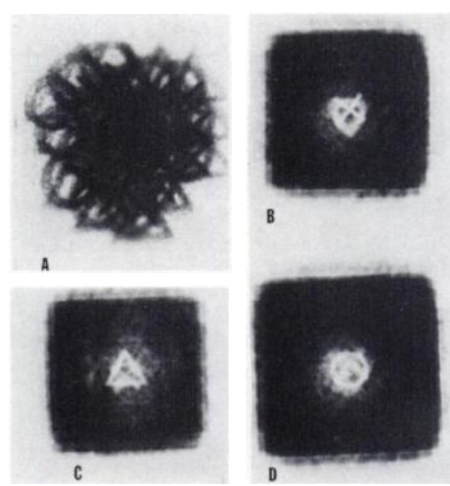

FIG. 2. (A) Coded shadowgram of cross, triangle, and circle. Patterns were spaced 2.5 cm in depth from one another. (B,C,D) Reconstructed images of each pattern.

Good resolution images of an x-ray-emitting extended object have been obtained using a nonredundant pinhole array and an incoherent white light source. The added burden of decoding the shadowgram is offset by the ability to obtain tomographic information with no sacrifice in lateral spatial resolution. The nonredundant nature of the pinholes results in a sharp image on a uniform background, which tends to minimize defects or artifacts in the image.

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