

High-Sensitivity Single-Photon Emission Computed Tomography (SPECT)

Safer, Faster, and More Accurate SPECT

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Abstract—A method and apparatus are described for high-sensitivity Single-Photon Emission Computed Tomography (SPECT). The apparatus includes a two-dimensional (2D) gamma detector array that, unlike a conventional SPECT machine, moves to different positions in a three-dimensional (3D) volume space near an emission source and records a data vector g which is a measure of gamma emission field. In particular, the 3D volume space in which emission data g is measured extends substantially along a radial direction r pointing away from the emission source, and unlike a conventional SPECT machine, each photon detector element in the 2D gamma detector array is provided with a very large collimator aperture. Data g is related to the 3D spatial density distribution f of the emission source, noise vector n , and a system matrix H of the SPECT apparatus through the linear system of equations $g=Hf+n$. This equation is solved for f by a method that reduces the effect of noise.

Keywords: *Single-Photon Emission Computed Tomography (SPECT), Positron Emission Tomography (PET), medical imaging, computed tomography.*

I. INTRODUCTION

This paper is based on U.S. Patent No. 8008625, issued to this author in August 2011. It relates to a method and apparatus for Single Photon Emission Computed Tomography (SPECT) in Nuclear Medicine. This method and apparatus are also applicable to Positron Emission Tomography (PET). The method and apparatus are specifically related to exploiting the information in the spatial intensity distribution of the three-dimensional (3D) photon emission field in a 3D volume space around an emission source. This information can reveal the 3D spatial density distribution of the emission source. In particular, the 3D volume space is designed to extend substantially along the radial distance pointing away from the emission source in order to obtain reliable results due to the inevitable presence of noise in measurements. The method and apparatus permit the use of very large collimator apertures, including the maximum possible of up to 180 degrees field-of-view, and therefore provide a very high-sensitivity SPECT

method and apparatus with the advantages of lower radiation dosage for patients, lower cost of procedure, and faster procedure.

Medical radionuclide imaging or nuclear medicine is an important diagnostic tool for obtaining three-dimensional (3D) maps of the distribution of a radiation emission source administered to a patient. SPECT is a commonly used radionuclide imaging technique. Gamma radiation detectors are used to record the emission from the patient's body. This recorded data is used to reconstruct the 3D spatial distribution of the emission source in the patient's body. This reconstructed image is useful in the diagnosis of problems in different organs such as kidney, blood-vessels, heart, lungs, bone, and brain.

SPECT machines in prior art have relatively low sensitivity because they use a small aperture or small field-of-view collimator for gamma detectors. About 99% or more of the gamma photons carrying useful information are blocked and wasted by these small aperture/field-of-view collimators. As a result, Signal-to-Noise ratio in the gamma emission measurements are very low leading to poor quality in reconstructed tomographic images. Large field of view collimators are not used as they result in highly blurred images with depth/distance dependent blur of the radiation emission source and reduce the spatial resolution of reconstructed tomographic images. Large collimator apertures also increase errors due to increase in the sensing of scattered gamma rays which make the reconstructed tomographic images less accurate. These limitations of using a large aperture collimators are prevalent in the SPECT methods and apparatus in prior art but they are not as much in the novel SPECT method and apparatus disclosed here.

The theoretical foundation of the conventional SPECT method and apparatus is based on the following theoretical result: *the tomographic reconstruction that provides the 3D spatial density distribution of a gamma emission source can be made from beam projection data, i.e. the measured values of the line-integral of the density of gamma emission source along*

different directions of view. Fourier-slice theorem states this result nicely for parallel projection data. See page 56 in the following book which is sold in book shops as well as freely available at www.slaney.org/pct:

A. C. Kak and Malcolm Slaney, *Principles of Computerized Tomographic Imaging*, Society of Industrial and Applied Mathematics, 2001. ISBN-10: 089871494X .

In practice, integral/sum of the attenuated intensity of emission source elements along a thin line is measured. The thickness and shape of the elements along the thin line in 3D space are determined by the collimator geometry, specifically the small aperture/field-of-view of the collimator. Attenuation of the emission is caused by the material substance around the emission source and through which the emission passes through before being measured. The measured line-integrals are called projection data or sinogram of attenuated emission. Projection data corresponding to different collimator structures such as parallel/converging/diverging-hole, fan-beam, cone-beam, etc., are used in prior art. However, all of this prior art is based on this theory of measuring and inverting line-integrals. When it becomes necessary to increase signal-to-noise ratio, i.e. increase sensitivity to information-carrying (non-scattered) gamma rays, the use of large apertures are forced by the rules of physics and geometry, and are accepted and used reluctantly. The distance/depth-dependent image blur of emission source caused by large apertures is treated as a serious undesirable problem. This depth dependent blur is reduced through one of several techniques that trade-off spatial resolution for errors due to noise in the reconstructed tomographic image. The gamma emission field is typically measured on a 2D planar surface that rotates around the emission source at a roughly constant/fixed distance/radius from an approximate center point of the emission source (see FIG. 3). The set of all points at which the emission field is measured forms a 3D surface with a small volume in the shape of a thin annular cylinder. In particular, this volume extends by a very small length along the radial dimension, but extends substantially much more along directions perpendicular to the radial distance.

A good description of conventional SPECT apparatus and method can be found in

1. P. C. Hawman, J. Qian; J. D. Treffert, "High-sensitivity SPECT imaging of small body organs using a multi-headscintillation camera with non-uniform collimation", US Patent No. 5,462,056, 10/31/1995.
2. G. T. Gulberg and G. L Zeng, "Three-dimensional SPECT reconstruction of combined cone-beam and fan-beam data", US Patent No. 5,565,684, Oct. 15, 1996.

A more recent development on a SPECT apparatus with a specially designed collimator structure that does not involve relative rotation between a patient and a gamma detector is reported in

E. G. Hawman, "Non-rotating transaxial radionuclide imaging", US patent No. 7521681 B2, 4/21/2009,

However, none of these include modeling and exploiting or measuring gamma radiation in a 3D measurement volume space that extends substantially along the radial direction. Therefore they have low sensitivity and the results are less reliable than the present invention. In prior art, SPECT/PET apparatus that measure gamma radiation at different angular positions tangential to a roughly circular contour around the object of interest is prevalent as the underlying theory for such apparatus is known to all persons skilled in the art. However, SPECT/PET apparatus that measure gamma radiation at different radial distances is not found anywhere except in the present invention. Such measurement along different radial distances was not considered in prior art perhaps because, based on intuition, it was assumed to provide no new information. There was no theoretical basis for such assumption as the new theory here proves this assumption to be wrong.