Published in final edited form as:

IEEE Nucl Sci Symp Conf Rec (1997). 2007 ; 6: 4275–4278. doi:10.1109/NSSMIC.2007.4437061.

Expanding SimSET to include block detectors:

performance with pseudo-blocks and a true block model

R. E. Schmitz [Member, IEEE], S. B. Gillispie, R. L. Harrison [Member, IEEE], L. R. MacDonald [Member, IEEE], P. E. Kinahan [Senior Member, IEEE], and T. K. Lewellen [Fellow, IEEE]

R. E. Schmitz is with the University of Washington, Seattle, WA 98195 USA (telephone: 206-598-5971, e-mail: rschmitz@u.washington.edu).

S. B. Gillispie is with the University of Washington, Seattle, WA 98195 USA (e-mail: gillisp@u.washington.edu).

R. L. Harrison is with the University of Washington, Seattle, WA 98195 USA (e-mail: roberth@u.washington.edu).

L. R. MacDonald is with the University of Washington, Seattle, WA 98195 USA (telephone: 206-543-3653, e-mail: macdon@u.washington.edu).

P. E. Kinahan is with the University of Washington, Seattle, WA 98195 USA (telephone: 206-543-0236, e-mail: kinahan@u.washington.edu).

T. K. Lewellen is with the University of Washington, Seattle, WA 98195 USA (telephone: 206-543-2365, e-mail: tkldog@u.washington.edu).

Abstract

We present a study that introduces two approaches to implementing block detectors into SimSET and compares their performance. SimSET is a photon tracking simulation package, which currently incorporates only detectors made of a solid annulus of scintillator material. A pseudo-block approximation has been imposed on the solid annulus of conventional SimSET by discarding interactions in annulus segments that span the angular block gap. This yields blocks that are annulus segments, not rectangles. This is a quick and easy approximation of block structure, which brings SimSET results closer to actual scanner measurements. Even better agreement is expected with a deeper modification of the SimSET code that implements true rectangular blocks in the detector module (to be released late 2007/early 2008). This approach enables the greatest amount of variability and trueness to detail.

We compare results from both block structure implementations to the conventional SimSET results and to measurements from a GE DSTE PET/CT scanner. Differences are evaluated in terms of sensitivities, crystal maps, and energy spectra, as well as in benchmark time tests of the simulation runs and their ease of use.

Either implementation of block structure can aid in improving simulation accuracy by ameliorating one known cause of discrepancies, the geometric nature of the block detectors.

I. Introduction

Monte Carlo simulations of positron emission tomography data are frequently used to predict system behavior for hypothetical systems for which no measured data exists for validation. This requires accurate predictions by the simulation package, because no fudge factors can be applied to bring the simulated data in line with measured results. Depending on the intended use of the simulation package, accuracy in predicting trends and a rank ordering of different scenarios might fulfill the expectations, or a more detailed prediction of absolute numbers

might be required. The Simulation System for Emission Tomography (SimSET) [1] generally performs very efficiently for the first type of simulation requirement, whereas often other more precise and much more time-consuming Monte Carlo packages (such as GATE [2]) are required for the second type. Which package to use is usually a trade-off between desired detail and necessary compute-time.

Here, we introduce and compare the performance of two different extensions of the SimSET package, which add the effects of a block structure detector system to the simulations. The simple approach is to impose segment-shaped gaps after running the photons through the regular SimSET solid detector annulus yielding a pseudo-block structure output. This is an internal extension of SimSET. The second approach is a deeper modification of the SimSET code that replaces the solid annulus with true rectangular blocks in the detector module [3]. This full extension is to be released in late 2007/early 2008.

II. Methods

A. SimSET Expansions for Adding Block Structure

We extend the Monte Carlo Simulation package SimSET with two different methods to include the effects of block structure as an aid in producing more realistic simulation results:

1) Pseudo-Blocks—The pseudo-block approach makes use of a user routine that is built into SimSET (PhgUsrBin). It is invoked after a photon has traversed SimSET's regular detector module with the solid annulus. It can alter the photon's detection parameters. This method breaks up the scintillator annulus into angular segments that correspond to blocks and the gaps between them (see Fig. 1). This means that the resulting pseudo blocks are not rectangular.

All interactions in gaps are discarded and the remaining interactions are summed in each segment block separately. The centroid in the block with the highest energy sum is adjusted to the center of the corresponding crystal (assuming no gaps between crystals) and the crystal element number is determined (ring number and the crystal number around the ring). The energy can then be blurred differently as a function of crystal position.

The new position and energy information are stored for this photon and it is sent to SimSET's binning module. Finally, another user routine is called to replace SimSET's default sinogram binning indices (r , θ) with crystal element indices.

2) Full Blocks—The full block approach adds an extra model to the detector module where true block detectors can be defined [4]. The blocks can be arranged as desired around the simulated field of view (see Fig. 2). Layers of absorber, detector housing and similar structures can be placed in between the different elements.

In this first version, the blocks are still solid pieces of scintillator (i.e. there is no crystal separation inside blocks), though later versions will allow the blocks to be sub-divided. This deeper modification incorporates the block structure directly into the photon tracking process, so that each photon is tracked through blocks and gaps in the detector module.

Binning is by crystal element index and uses the same user-routine as introduced for the pseudo-block model.

B. Evaluation of Results

We compare results from the pseudo-block method to conventional SimSET without blocks and to measurements taken on our GE DSTET PET/CT scanner. For some measurements, we also compare to the results from the full block model. However, the true block model is still

under validation testing, therefore only partial results are presented. We will publish the fully validated results separately once they become available.

We used the enhanced NEMA NU 2-2001 count rate phantom with three possible diameters (20, 27, and 35 cm) for our measurements and simulations and obtained single photon and coincidence (true and scattered) count rates.

Measured data are taken on a GE DSTe PET/CT scanner in three collimation modes: 2D (full collimation), 3D (no collimation), and 2.7D (a partial collimation mode [5]).

Corresponding simulation results are obtained for these measured data sets with the currently released SimSET version 2.6.2.6 (no-blocks version and version with pseudo-blocks) and with the new version 2.9 (for full blocks).

No importance sampling is used in either version, and all reported simulation times are from runs on a single processor of a 2 MHz G5 Mac OS X Server.

Differences between the different simulation methods and the measured data are evaluated in terms of sensitivities, crystal maps, and energy spectra, as well as in benchmark timing tests of the simulation runs.

Sensitivities are determined from a decay series count rate acquisition. The sensitivity is the slope of the count rate curve at its lowest activity end (only true and scattered coincidences present, no randoms). Here we present a comparison of both block implementations, of SimSET without blocks, and of the measured data.

Crystal maps are obtained from the NEMA count rate data at an activity of about 10mCi. The measured count rate per crystal element is depicted for a subset of all blocks and compared to the respective distributions from SimSET with and without the pseudo-block model. (No data from SimSET with the full block model is shown.)

All simulation results are corrected for any (residual) packing fraction and for livetime as measured in the corresponding data frame.

III. Results

A. Sensitivities

The comparison of the predicted and measured sensitivities is given in Table 1 for single photons and in Table 2 for coincidences. Conventional SimSET generally over-predicts the sensitivities to single photons and coincidences. Because the pseudo-block structure discards interactions in the block gaps, it lowers these numbers, bringing them closer to the measurements. The full-block model agrees with the pseudo-block simulation trends, however the exact numbers may still change through the validation process.

B. Visual Block Structure Comparison — Crystal Maps

A visual comparison of the effect of adding blocks is given in Fig. 3. It shows the average singles rate per detector over a 5×4 array of blocks. The 8×6 crystals per block show up well on top of the expected axial (geometric) sensitivity distribution.

Fig. 3 shows the axial and transaxial sensitivity patterns for measured data and simulations. The pseudo-block approach shows obvious improvements compared to the non-block SimSET results.

Fig. 4 shows a quantitative view of the axial and transaxial sensitivities to singles photons in 3D mode in measured data and simulations with and without pseudo-blocks. The pseudo-block code recreates the sensitivity dips at block edges quite well and leads to a much closer agreement with the measured distributions.

C. Timing

The pseudo-block method is quick to set up and implement (only 17 input parameters needed) and does not add noticeably to SimSET's reasonable computation times. The true block method is more time-consuming to set up due to the large number of input parameters needed (on the order of 780 in our case), though an input assistant substantially reduces this burden for tomographs with regular geometries. The true block method also increases computation time. However, the new version (2.9) includes other, independent efficiency improvements that yield a net decrease in computation time even with the use of the full-block detector.

Benchmark CPU timing results are compared in Table 3 for single SimSET runs with the two block models. 1.2 billion photons (or 600 million annihilation events) are modeled per run. The speed-up is substantial but unrelated to the block model changes. It instead reflects the efficiency changes in the new SimSET version 2.9.

IV. Summary

SimSET can be expanded to include block effects in two ways, where both produce a better agreement with measured data in terms of single photon and coincidence sensitivities than the regular SimSET code (solid annulus). SimSET with pseudo blocks also improves the agreement of measured distributions axially and transaxially (no data for true blocks yet). We expect that the full block model will yield even closer agreement with measured data once all validation testing has been completed.

The full block model will be made available through the upcoming SimSET release 2.9 (expected towards the end of 2007/beginning 2008).

Either implementation of block structure can aid in closing the gap between simulation and real clinical scanner results by ameliorating one known cause of discrepancies, the geometric nature of the block detectors. We hypothesize that the answer to which block model to choose over the other will depend on the problem posed.

Acknowledgements

This work was supported in part by a grant from GE Medical Systems and by National Institutes of Health PHS grant CA42593.

References

- [1]. Lewellen, et al. Monte Carlo Calculations in Nuclear Medicine. Ljungberg, et al., editors. Inst. of Phys. Publ.; 1998. p. 77
- [2]. Jan, et al. Phys. Med. Biol 2004;49:4543. [PubMed: 15552416]
- [3]. Shokouhi, et al. IEEE Trans. Nuc. Sci 2004;52(51):1305.
- [4]. MacDonald, et al. IEEE NSS CR 2006;4:2488–2493.

Fig. 1. Exaggerated schematic of pseudo-block implementation in SimSET, demonstrating difference between true rectangular blocks used in the DSTE and in the true block simulation and the pseudo-blocks (segments).

Fig. 2. Example of a PET detector built with rectangular blocks in 3 axial rings in SimSET. Note that for our simulations, the detector blocks form a polygon detector shape, instead of detector banks as in this illustration.

Fig. 3. Comparison of crystal maps (singles counts per crystal). Shown is a schematic of the array placement in the scanner ring and the maps from the DSTE measurement, and SimSET with and without pseudo-block approach.

Fig. 4. Axial (top) and transaxial (bottom) sensitivities in 3D mode from SimSET, from DSTE measurements, and from simulations with and without pseudo-blocks.

Table 1

Single Photon Sensitivities [Mcps/mCi]

		DSTE Measured	SimSET no Blocks	SimSET Pseudo Blocks	SimSET True Blocks
2D	20 cm	1.07	1.02	0.97	1.02
	27 cm	--	0.81	0.77	0.81
	35 cm	0.56	0.64	0.60	0.63
2.7D **	20 cm	1.79	2.10	1.97	2.05
	27 cm	1.66	1.65	1.54	1.61
	35 cm	1.24	1.26	1.18	1.23
3D	20 cm	2.79	3.40	3.21	3.27
	27 cm	2.55	2.67	2.51	2.56
	35 cm	1.71	2.04	1.93	1.96

** 2.7D denotes a partial collimator that compared with 2D has only one out of three septa.

Table 2

Coincidence Sensitivities [kcps/mCi]

		DSTE Measured	SimSET no Blocks	SimSET Pseudo Blocks	SimSET True Blocks
2D	20 cm	14.84	19.48	16.27	16.71
	27 cm	--	11.61	9.68	9.88
	35 cm	4.06	6.10	5.10	5.21
2.7D **	20 cm	42.35	66.07	54.44	56.47
	27 cm	31.99	40.70	33.61	34.71
	35 cm	18.07	22.54	18.47	19.29
3D	20 cm	66.10	107.87	88.03	90.79
	27 cm	49.08	68.11	55.72	57.40
	35 cm	25.55	38.84	31.79	32.69

** 2.7D denotes a partial collimator that compared with 2D has only one out of three septa.

Table 3

SimSET Benchmark timing results

	CPU time [sec] per run on a 2MHz G5 Mac OS X Server	
	Coincidences	Single photons
SimSET v2.6.2.6 with pseudo blocks	34,779	95,201
SimSET v2.9 with true blocks	12,555	67411