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Forward Problem Model Neighborhood Relations Based on the Monte Carlo (MC) Simulation Photon Fluence Distributions

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Abstract: Forward problem model was created for the continuous wave (CW) biomedical diffuse optic imaging (DOI) modality. Forward problem model weight matrix functions were calculated based on the photon's Monte Carlo (MC) particle simulation model. Photon was thought as a particle, scattering and absorption events were acted inside the imaging tissue model. Doing this work has two main parts, the first part is running MC simulation program, the second part is transferring MC photon fluencies from ANSI Standard C programming environment to the image reconstruction platform, then translating or interpolating the photon fluence distributions based on the imaging tissue mesh grid geometry, finally building the forward problem model weight matrix by multiplying photon fluencies under each source and detector positions. MC photon propagation code was run for seven-layer head model in ANSI standard C programming compiler under the Cygwin prompt. Absorption (μ_a), and scattering (μ_s) tissue optic coefficients were selected as tough to mimic human head. Multi sources and detectors were placed on imaging tissue, which is slab back-reflected geometry. Between each source and detector positions, calculated MC photon fluence distributions were transferred from ANSI standard C code output data and translated by mathematical interpolation method to image reconstruction program mesh grid geometry. In order to do that, multi-source and detector matches were grouped into sub-classes. Each class has different source-detector distance (SDS) group. Forward problem model weight matrix functions were calculated and drawn in xy bird-eye and yz side-view. They were observed as they were predicted, successfully. This work involves grouping the same neighborhood weight functions appropriately.

Keywords: Monte Carlo (MC) simulation photon fluencies, Forward model weight matrix

Introduction

Forward problem model is preparing the photon migration inside the imaging tissue. Photon fluencies can be prepared by using theoretical physics photon wave approximation, which is originally taking its bases from Radiative Transport Equation (RTE) or photon as a particle model, which is prepared by Monte Carlo (MC) simulations. For this work, Monte Carlo (MC) photon-tissue interaction program was run to generate photon fluencies inside the appropriate tissue model [1, 2]. Isotropic light source photons were propagated inside the tissue from tissue surface source position. Photon particle was sent through tissue from tissue surface like collimated light source, which is perpendicular to tissue surface in MC simulation. MC simulation program is run based on the cylindrical (r, z) or cartesian (x, y, z) coordinate system. Cylindrical coordinate system approach is much faster than three-dimensional (3d) Cartesian coordinate system. Depend on the tissue absorption (μ_a) and scattering (μ_s) optical parameters, photon paths occur naturally. Diffusion event occurs and photon migration varies inside the imaging tissue depend on the tissue absorption (μ_a) and scattering (μ_s) optical parameters. Photon's mean free path (mfp) is the distance between two collisions of photon with molecules inside the tissue. This is called as step size. The step size is calculated based on the probabilistic distribution of photon's mfp between two consecutive collisions. Different tissue types have different absorption coefficients (μ_a). Photon is losing its initial weight while it is taking the step inside the tissue defined by scattering coefficient (μ_s). Azimuthal and deflection angles are calculated according to the MC simulation random number generator (RNG). RNG generates the random number in MC simulation program. Once the angles were determined, photon moves inside the tissue. While it is propagating inside the tissue, angles are calculated repeatedly in each step. MC simulation code steps are illustrated in Fig.2. After MC simulation program code was run, finally, total photon migration and photon fluence distribution are defined. Photon

fluence distribution is then transferred into the data analyze program for spectroscopic or tomographic purposes. Diffuse Optic Tomography (DOT) researchers benefit from photon fluence distributions inside the imaging tissue model. For DOT model, different geometric approaches might be used such as, back reflected, transmission-through, or circular or cylindrical ring model. Most of the breast imaging works had been done based on the circular ring geometry. Laser sources and photo-detectors (PDs) are placed around the circular ring, which covers the breast. Some Continuous Wave (CW) breast imaging studies also used back-reflected geometry model [3]. In back-reflected geometry, sources and detectors are placed on the planar surface. Source and detector positions can be selectively varied depend on the research methodology. Some researchers select the chessboard shape for appropriate source and detector placement and source-detector-distances (SDDs). In this work, bifurcated source and detector placement topology was used.

Method

Diffuse Optical Tomography (DOT) Forward Model Problem

MC simulation program codes were run in cylindrical geometry for a given radial r and depth z distances, the photon fluence distributions were obtained by MC simulation program. They were transferred into the geometric data analyze and diffuse optic tomography (DOT) image reconstruction algorithm environment [4, 5]. Single source photon fluence distributions should be distributed for all source-detector neighbors, since the back-reflected geometry has multi probe couplings, which run in back reflection geometry for multi elements [6-8]. The photon fluence distributions from source positions were multiplied by the photon fluence distributions from detector positions. Each source and detector has its own photon fluence distributions inside the imaging tissue medium. These two different photon fluencies were multiplied to be able to calculate the forward model weights between each source and detector positions. It has multi source and detector matches. Fig.1 is showing photon fluence density distributions obtained at a radial distance of r from a source position and depth z from MC simulation. This figure was drawn according to the MC simulation photon fluencies, which then translated, from 2d to 3d by interpolation method. Tissue head model was used for seven layers, epidermis, dermis, scalp, skull, Cerebrospinal Fluid (CSF), gray and white matters. Absorption (μ_a) and scattering (μ_s) tissue optic parameters were selected based on the head model, appropriately. Laser wavelength for this specific tissue type is 800 nm. Image reconstruction mesh grid coordinates were (x, y, z) = (5 cm, 5 cm, 5 cm). Ngrid = 30*30*30 = 27000. Deposited energy and photon fluence distributions can be seen from Fig.1, for different head layers.

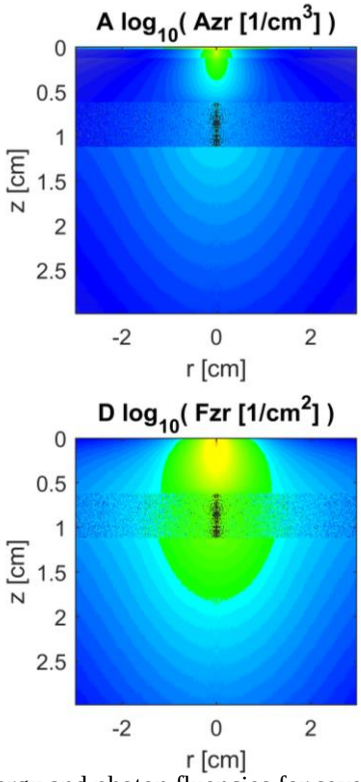

Figure 1. Deposited energy and photon fluencies for seven-layer head model

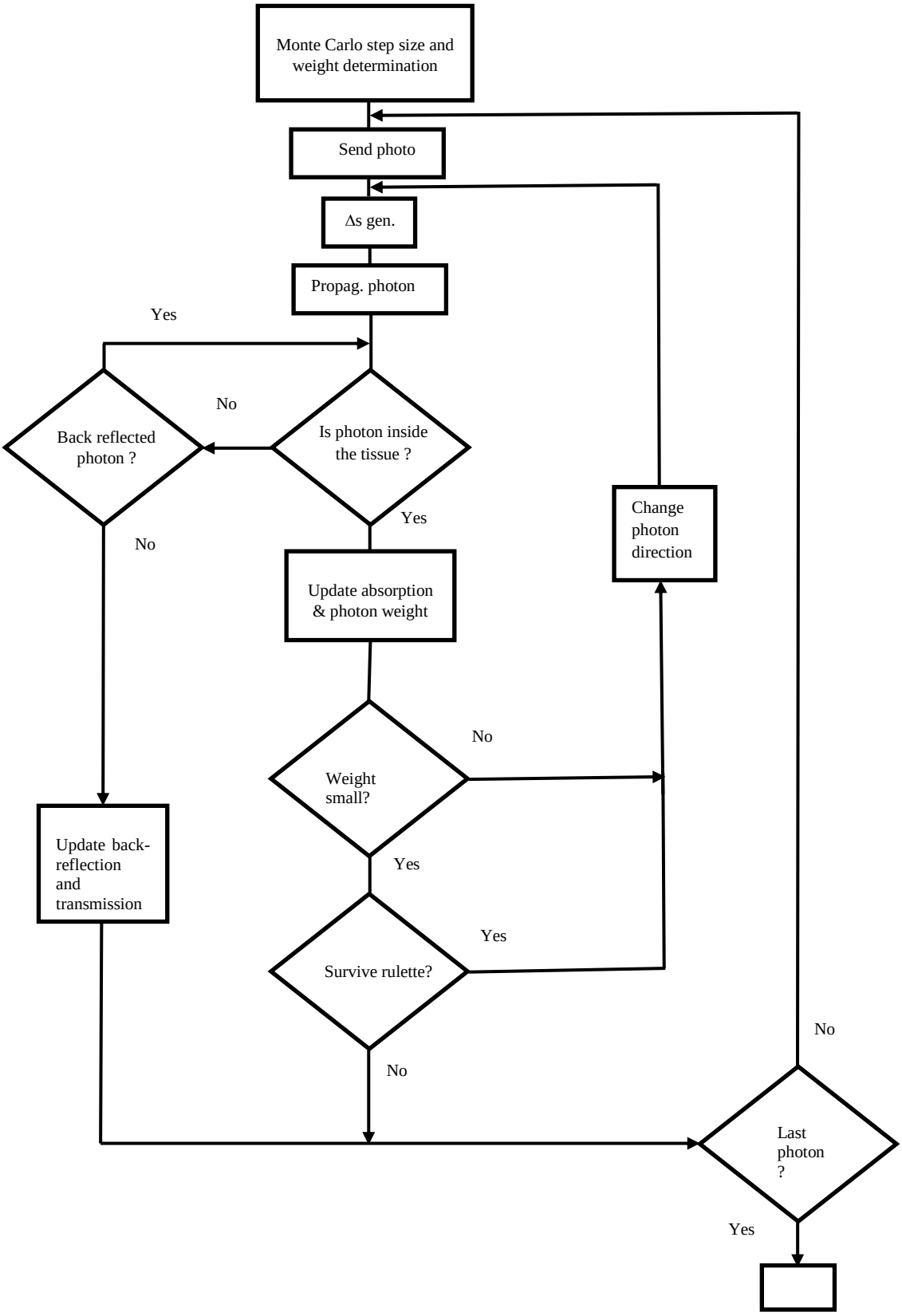

Figure 2. Monte Carlo (MC) simulation program state-diagram

Results and Discussion - Photon Fluencies

This work had 45 sources and 45 detectors in the back-reflected plane geometry with bifurcated source and detector positions. Totally 223 different neighborhoods existed. Each neighborhood has different number of matchups. Fig. 6 was drawn between source and detector positions, which are seen according to the neighborhood numbers. As it can be seen from the bird's-eye view, banana-like trajectories occurred. The generated banana-like trajectories are being used in perturbation equations, according to the image reconstruction algorithms.

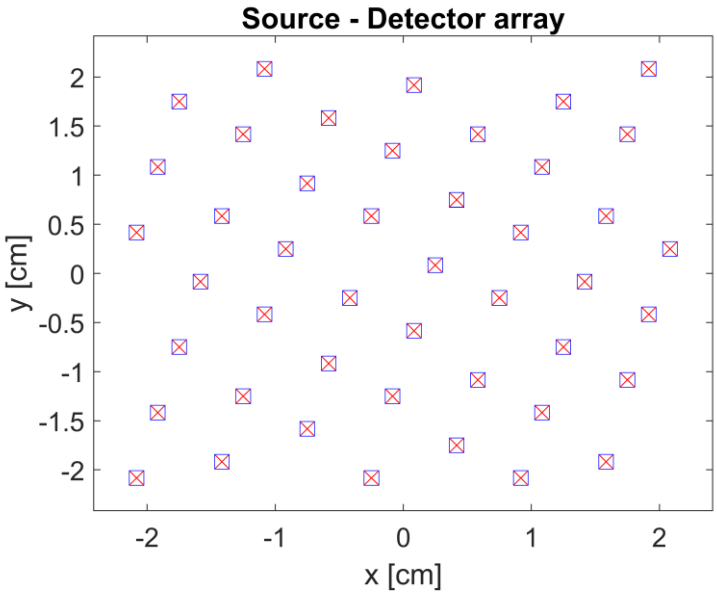

Figure 3. Bifurcated 63 source and 63 detector locations

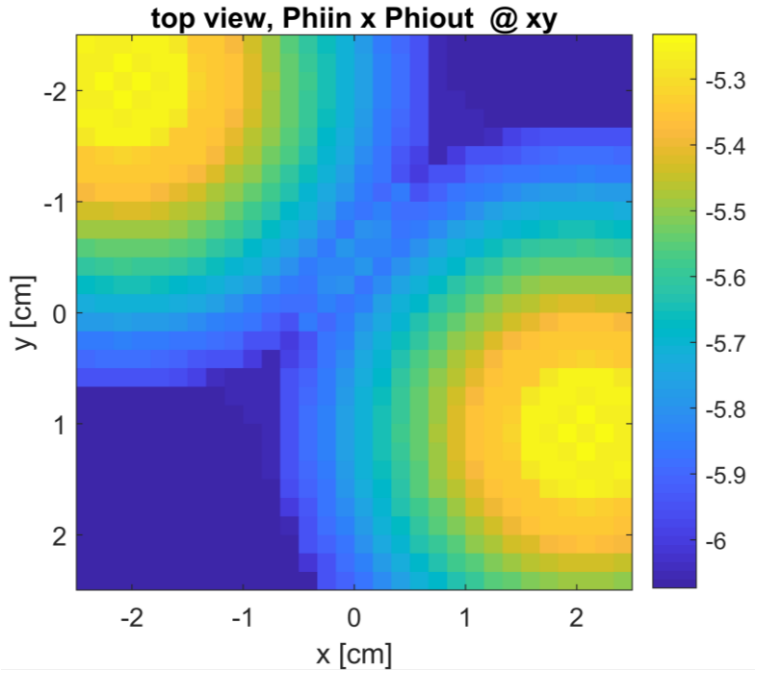

Figure 4. 1st source and 63rd detector photon fluencies in bird-eye view

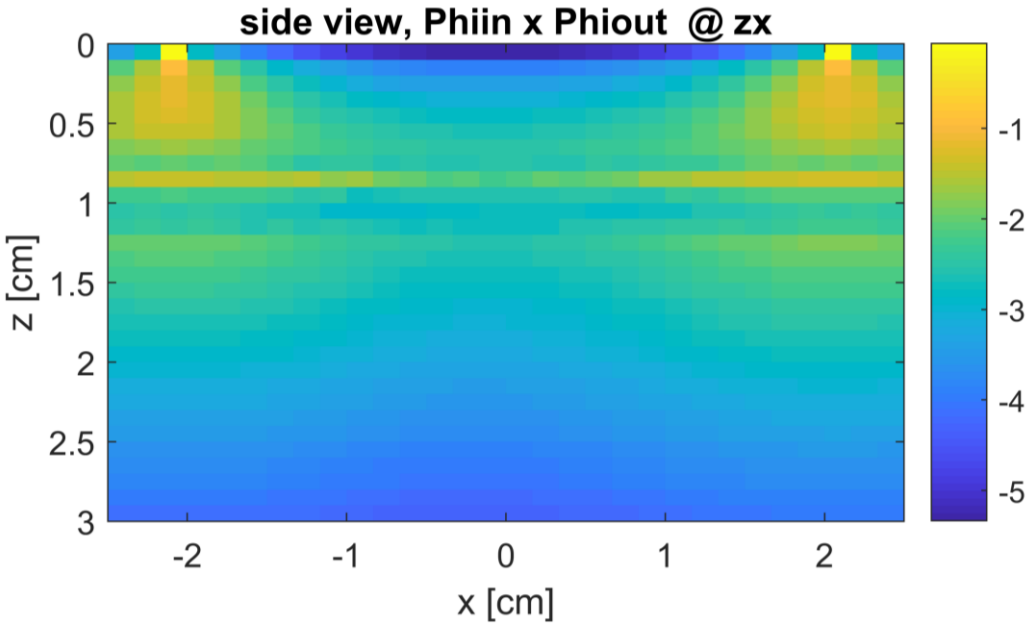

Figure 5. 1st source and 63rd detector photon fluencies in side-view

Fig. 4 and Fig. 5 are showing photon fluence distributions between 1st source and 63rd detector from bird-eye and side-view, respectively. In Fig. 5 banana shape can be realized between source and detector position. Since there are seven different kind of tissue types for head model, such as epidermis, dermis, scalp, skull, cerebrospinal fluid, gray and white matter, banana shape is dashed.

Conclusion

All matches were drawn between each source and detector position. However only one forward model photon fluence functions were illustrated for each neighborhood. Forward model weight matrix coefficient functions were calculated for back-reflected CWDOT imager geometry. The imager device simulation has 63 source and 63 detector locations based on the back-reflected slab geometry tissue-imaging model as bifurcated positions, which sources and detector are in the same xyz coordinates. CWDOT modality is one of the three basic run mods of biomedical optic imaging field, which are continuous wave (CW), time resolved (TR), and frequency domain (FD). DOT imaging modality has forward and inverse problem models. Forward problem model constitutes photon fluence distributions inside the imaging live tissue that is defined by scattering (μ_s) and absorption (μ_a) coefficients for different kind of tissue types. In this work, forward model was created by using and compiling MC photon-tissue interaction simulation program code, which was originally written in ANSI Standard C program compiler. After photon fluencies were generated, they were transferred and translated into the data analyze and image reconstruction program. Forward problem model functions were generated by multiplying each source and detector position's photon fluence distributions inside the imaging tissue geometry. Forward model weight matrix functions were illustrated in two-dimensional (2D) pictures for different neighborhood matchups in xy bird-eye view. 1st, 2nd, 7th, 12th, 16th, 31st neighborhoods were shown in Fig. 6.

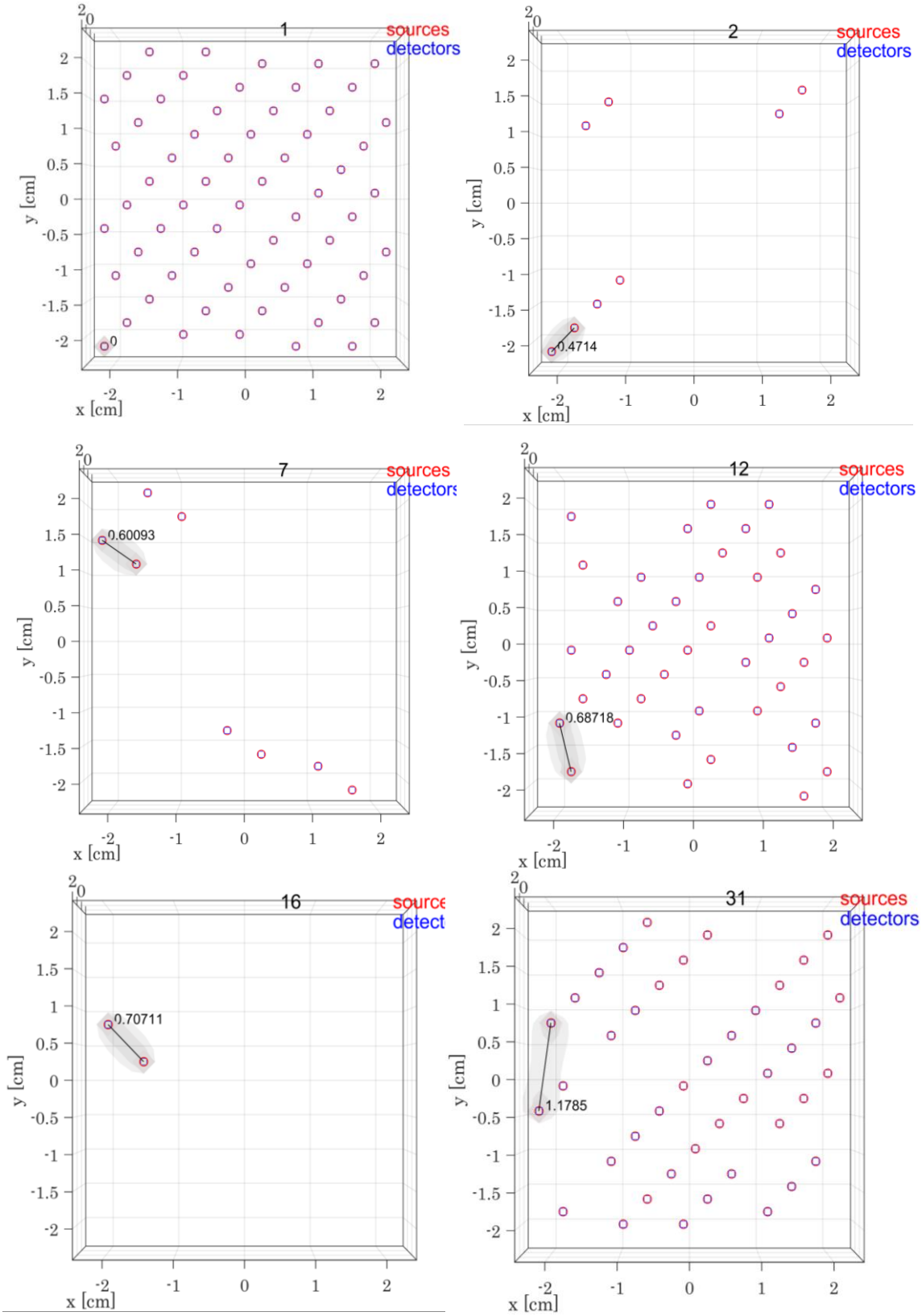

Fig. 6. 1st, 2nd, 7th, 12th, 16th, 31st neighborhoods bird-eye view photon fluencies

Recommendations

Photon fluencies were multiplied for each source and detector locations in back-reflected geometric model. This method constitutes of new photon translation methodology which is taking its data from MC simulation program run out data. It is necessary to transfer required MC output data from ANCI Standard C programming environment into the data analyze and image reconstruction program. However, using one program environment might have been better, since only one program would have been used. Second image reconstruction and data analyze program then might be retreated. By this way, program run times consume less than using two different program environments, clearly. Only C program might be chief executive.

Acknowledgements or Notes

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