Stepwise Linear Regression Modeling of the Point Spread Functions of a Multi-Pinhole SPECT Camera for I-123 DaTscan Imaging

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Abstract — **We investigate PSF modeling strategies for clinical I-123 DaTscan imaging on a dual-headed mixed collimator SPECT system consisting of fan and multi-pinhole (MPH) collimators on separate heads. The MPH component of this system proposed provides high-resolution imaging of activity in the structures of interest: the putamen, caudate and substantia nigra (SN), which lie in the central interior portion of the brain. In many multi-pinhole (MPH) SPECT imaging systems, improvement in image quality has been demonstrated with accurate modeling of the system point spread function (PSF) within reconstruction. To facilitate faster reconstruction and smaller memory overhead, simple PSF models are preferred such as a Gaussian. In many geometries a Gaussian model is reasonably accurate for the PSF. However, for different pinhole aperture shapes such as square or rectangular, and angled pinhole aperture planes, the measured PSF including all physical effects such as penetration and depth of interaction can have substantial non-Gaussian components. In this work, we illustrate with examples from our MPH collimator how stepwise regression analysis can be used to develop a generalized but parsimonious model for complex PSFs without a-priori knowledge of the exact analytical form of the PSF.**

Keywords— Point spread function (PSF), regression, SPECT

I. INTRODUCTION

Pinhole collimators have found application clinically in cardiac [1] and brain [2] SPECT imaging. System modeling and calibration have been key to improved image quality with such applications [3, 4]. Analytical, experimental, and Monte Carlo methods can be used to generate point spread functions (PSF) for determination of the system response matrix [5]. Full measurement of each location and storage of the PSF can require significant acquisition times and may require 10 TB or more for storage. Thus modeling of an array of measured PSF locations with storage of model parameters and interpolation between these parameters for non-measured locations can be employed to reduce acquisition, storage, and reconstruction time. In many geometries a Gaussian model is reasonably accurate for the PSF. However, for different pinhole aperture shapes such as square and angled pinholes, the measured PSF including all physical effects such as penetration and depth of interaction can have substantial non-Gaussian components [6,7].

In this work, we illustrate with examples from our MPH collimator to be combined with a fan-beam collimator for striatal brain imaging [8] how stepwise regression analysis [9] can be used to develop a generalized but parsimonious model for complex PSFs without a-priori knowledge of the exact analytical form of the PSF. Regression analysis allows the exploration (data-mining) of the measured PSF to determine the impact of including or excluding the higher order polynomial terms if present.

II. METHODS

Monte-Carlo simulation of MPH geometry in GATE is used to obtain the PSFs for a grid of point sources. As illustrated in Fig 1 each measured PSF is then normalized, ϵ = 0.0001 added (to avoid computation error for those projection pixel values outside the PSF region which have a value of 0), logarithm-transformed and fitted by stepwise regression fit using polynomials. The required order of polynomials was determined by assessing the normalized root mean squared error (NRMSE) and goodness of fit (R-squared) measures of polynomials of order 2 to 5. Polynomial of order 3 was determined to be sufficient for all the pinholes in our MPH system. Stepwise regression produces a fit with 10 coefficients for terms: 1, x, z, x^2, $x*z$, z^2, x^3, x^2*z, $x*z^2$, z^3 with a NRMSE < 10%.

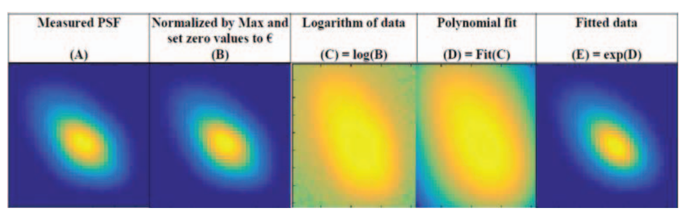

Figure 1- Schematic of PSF fitting using regression analysis (natural logarithm ($\log_e$(B)).

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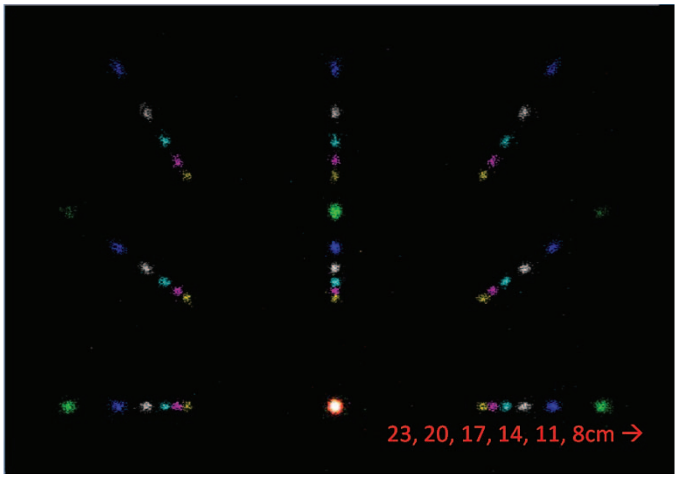

Figure 2- Overlay of the projections from a single point source placed directly in front of the Direct Pinhole at planes perpendicular to the Y-axis with distances ranging from 8 cm to 23 cm with increments of 3 cm. For the point source located at 8 and 23 cms from the pinhole aperture, the projections are shown in green and yellow colors respectively.

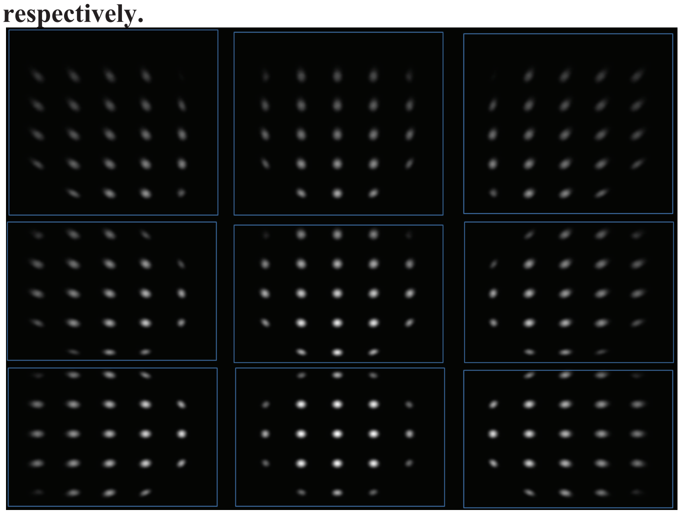

Figure 3- Projection of a grid of 25 (5X5) point sources placed at a plane 14 cm from the aperture plane. The nine regions demarcated by boxes enclose the projections of the grid for the nine pinholes.

III. RESULTS

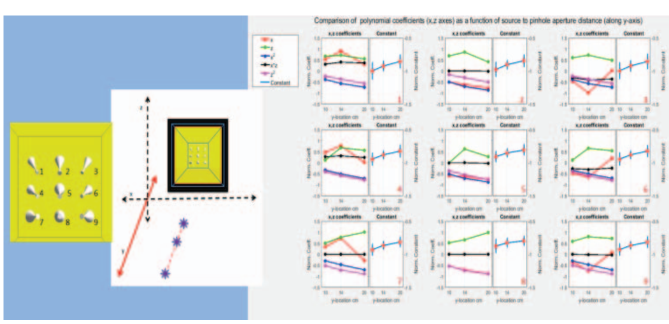

Figure 4(a)- Variation of PSF Coefficients along Y (distance from collimator face) direction.

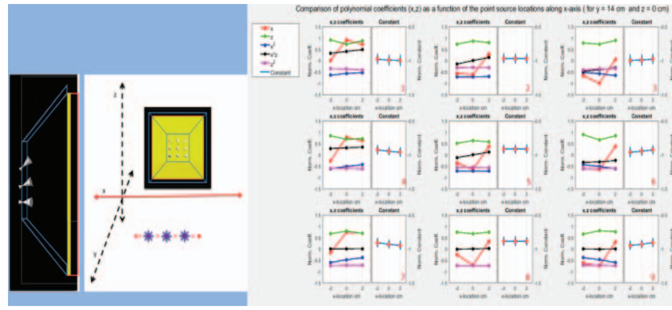

Figure 4(b) - Variation of PSF Coefficients along X (lateral or side to side) direction.

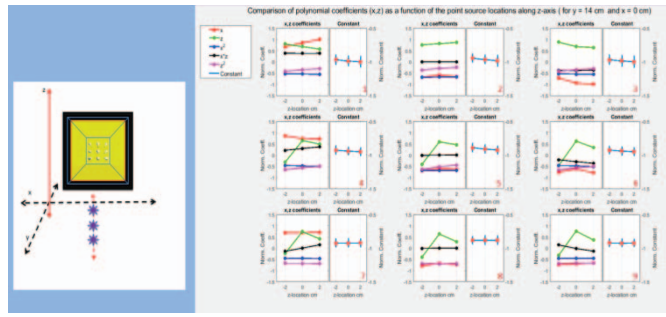

Figure 4(c) - Variation of PSF Coefficients along Z (caudal to cranial) direction.

The plots of Fig 4 depict the variation of the coefficients of the fitted PSF with distance along Y (Fig 4a), X (Fig 4b) and Z (Fig 4c) axes in the volume of interest. The orientation of the axes and the X-axis of the plot are shown in the graphic on the left of the plots. Only the significant terms of the 3rd order polynomial fit are shown as the other coefficients are close to zero. The layout of the plots corresponds to the layout of the pinholes, which is also shown on the left. The intercept (constant term) is much larger in magnitude than all the other coefficients and is shown in the right pane for each pinhole. It is normalized to the maximum value for each plot. All other coefficients are shown on the left pane for each pinhole and are normalized to the maximum of all the coefficients.

IV. CONCLUSION

Stepwise regression can be used to fit generalized but compact PSF models for system modeling within reconstruction. NRMSE results showed that the stepwise regression fit reduced the fitting error compared to the 2D Gaussian method for the most oblique pinholes. The regression fit method analyzes all possible interactions between predictors up to the specified model order to reduce the model to terms that explain most of the variance in the data. After fitting the PSF data, the method can be applied to parameterize the coefficient variation over the volume to obtain a simplified look-up table for use in reconstruction.

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REFERENCES

[1] W. L. Duvall, L. B. Croft, T. Godiwala, E. Ginsberg, T. George, and J. H. Henzlova, “Reduced isotope dose with rapid SPECT MPI imaging: Initial experience with a CZT SPECT camera,” *J Nucl. Cardiol,* vol. 17, no. 6, pp. 1009-1014, 2010.

[2] F. J. beekman, "G-SPECT: Changing the Game of Clinical SPECT," MILabs, ed., 2015.

[3] Y.-C. Chen, L. R. Furenlid, D. W. Wilson, and H. H. Barrett, "Calibration of scintillation cameras and pinhole SPECT imaging," *Small-animal SPECT Imaging*, M. Kupinski and H. Barrett, eds., pp. 195-2001: Springer, 2005.

[4] B. W. Miller, R. Van Holen, H. H. Barrett, and L. R. Furenlid, “A system calibration and fast iterative reconstruction method for next-generation SPECT images,” *IEEE TNS,* vol. 59, no. 5, pp. 1990-1996, 2012.

[5] P. Aguiar, F. Pino, J. Sliva-Rodriguez, J. Pavia, D. Ros, A. Ruibal, and Z. El Bitar, “Analytical, experimental, and Monte Carlo system response matrix for pinhole SPECT reconstruction,” *Med. Phys.,* vol. 41, no. 3, pp. 032501-1-10, 2014.

[6] C. Cloquet, F. C. Sureau, M. Defrise, G. Van Simaeys, N. Trotta, and S. Goldman, “Non-Gaussian space-variant resolution modelling for list-mode reconstruction,” *Phys Med Biol*, vol 55, no. 17, 5045, 2010.

[7] S. Y. Chun, J. A. Fessler, and Y. K. Dewaraja, “Correction for collimator-detector response in SPECT using point spread function template,” *IEEE TMI*, vol 32, no 2, 295-305, 2013

[8] M. A. King, J. M. Mukherjee, A. Konik, I. G. Zubal, J. Dey, and R. Licho, “Design of a Combined Fan and Multi-pinhole Collimator Combination for I-123 DaTscan Imaging on Dual-headed SPECT Systems.,” *IEEE TNS,* vol. 63, pp. 90-97, 2016.

[9] N. R. Draper, and H. Smith, Applied Regression Analysis. Hoboken, NJ: Wiley-Interscience, 1998. pp. 307–312, implemented in MATLAB Statistics and Machine Learning Toolbox, Stepwise Regression Fit.