A Novel Kernel-Weighted Back-Projection Reconstruction Algorithm for Compton Camera Imaging

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INTRODUCTION

Compton camera imaging algorithms utilize the position and energy depositions due to double- or triple-scattered events of high-energy (>3 MeV) gamma rays within the detector system of Compton cameras to estimate the true location of a gamma source. The existing Compton camera imaging algorithms such as filtered back projection (FBP)[1], list-mode maximum likelihood expectation maximization (LM-MLEM)[2], and stochastic origin ensemble (SOE)[3] are not able to sufficiently suppress the background noise. In this study, we present a novel kernel-weighted back-projection (KWBP) algorithm which was developed specifically for prompt gamma imaging for use in proton therapy. The usage of KWBP algorithm can be extended to imaging of any gamma sources.

AIM

To develop and characterize a novel kernel-weighted back-projection (KWBP) algorithm that reduces noise in Compton camera imaging.

METHOD

A GPU optimized kernel-weighted back-projection (KWBP) algorithm for image reconstruction from the datasets measured by Compton Cameras was developed. In this algorithm, all the half-cones, which are derived from double or triple scattered events that contain the origin positions of gammas on their surfaces, are projected into a voxelated image space. The gamma emission probability in each voxel is calculated using the Epanechnikov kernel density of the minimum distance between the voxel center and the surface of each cone.

$$p(\vec{x}_{ijk}) = \frac{1}{Mh}\sum_m^M K\left(\frac{\left|\vec{x}_{ijk} - c_{m,\vec{x}_{ijk}}\right|}{h}\right)$$

Here $c_{m,\vec{x}_{ijk}}$ is the point of closest approach (PCA), defined as the point on the cone c_m closest to the voxel center $\vec{x}$. K is the Epanechnikov kernel function: $K(z) = 0.75(1 - z^2)$ for $|z| < 1$; $K(z) = 0$ otherwise, and h is the kernel bandwidth. M is the total number of Compton cones determined by using the measured dataset.

To suppress the noise in the image, all the cones are randomly shuffled and back-projected to the image space and the resulting image is subtracted from the calculated image. Two key parameters of the KWBP algorithm, namely bin-size and bandwidth that affect the quality of the images and ability to predict the true source location were characterized. Two identical prototype Compton cameras positioned orthogonally to the source were used to measure the 0.662 MeV gammas from a Cesium-137 source at four different locations.

RESULTS

A bandwidth value between 6 and 14 was found to best estimate the true locations of the source. The positions of the source estimated by KWBP reconstructed images were found to be off by **3.0±1.4 mm**, **3.8±1.4 mm**, **3.8±1.4 mm**, and **8.4±1.4 mm** from their respective true positions. The location of the fourth source was much further away than the other three locations from the CCs. A voxel size greater than 20 x 20 x 20 mm^3 had no effect on the accuracy of source location, and that source location accuracy decreased with distance from the source.

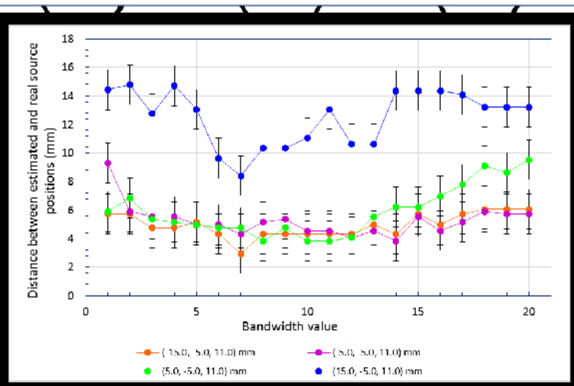

Figure 1: *The distance between an estimated source position and the real position of a button source (Cesium – 137), calculated from the images obtained with different bandwidth values. Each plot was obtained at a fixed source position, as shown in the legend.*

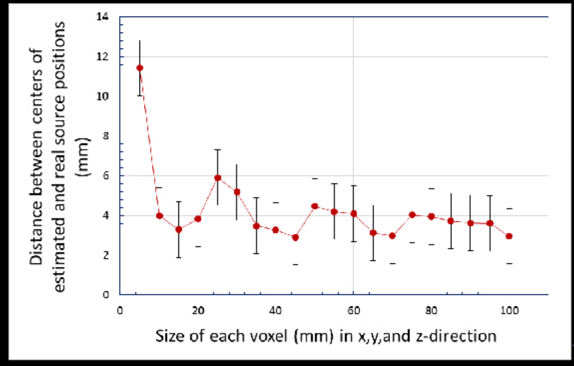

Figure 2: *Accuracy of source location, determined by distance from an estimated to the true source location, as a function of reconstructed voxel size.*

CONCLUSION

Leading Compton Camera imaging reconstruction algorithms such as back-projection and list-mode maximum-likelihood expectation maximization do not account for noise. The noise suppression ability of kernel-weighted back projection algorithm improves the efficiency of Compton Camera imaging and can be used to improve the online range verification of proton therapy.

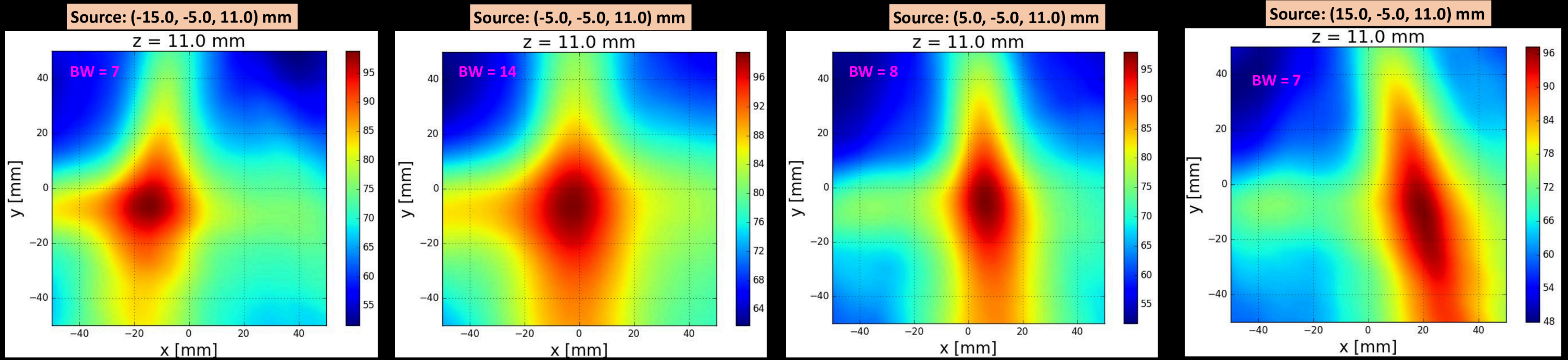

Figure 3: *KWBP reconstructed images of the Cesium -137 source placed at four different locations indicated on the top. Each plot was obtained with the bandwidth parameter that minimized the distance between the estimated and real positions of the source from Figure 1.*

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