Spatially variant point spread function for PET rigid motion correction

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Abstract—Positron emission tomography (PET) scanners usually present a spatially variant loss of spatial resolution. In addition, in scans where the subject can move across the scanner field of view (FOV), e.g. scans of freely moving animals, the loss of spatial resolution is motion dependent. The scanner spatially variant point spread function (SVPSF) can be estimated and then the loss of spatial resolution can be compensated by using resolution modeling. For motion correction reconstruction incorporating resolution modeling, the motion dependence of the SVPSF needs to be considered. Here we propose a method to calculate the motion dependent and spatially variant PSF for resolution modeling in motion correction reconstruction, using an asymmetric Gaussian model for the SVPSF. The SVPSF using the asymmetric Gaussian model produced a more uniform spatial resolution over the entire scanner FOV. Compared to a spatially invariant Gaussian model, the motion dependent SVPSF produced improved spatial resolution in motion corrected reconstructions of a resolution phantom. Using the motion dependent SVPSF in motion correction reconstruction improves spatial resolution and quantification in PET reconstructions. Therefore, scans of freely moving animal can benefit from using this method.

I. INTRODUCTION

The spatial resolution of positron emission tomography (PET) images is determined by several factors such as detector size, positron range, photon acollinearity and depth of interaction [1]. The spatial resolution is spatially variant and loss of spatial resolution occurs towards the edges of the FOV along the radial direction due to the parallax effect.

In addition, in the context of awake small animal brain PET where rigid motion correction is performed [2], the spatial resolution of the images is motion dependent as the animal can move over the entire field of view (FOV).

In motion-free reconstruction, using iterative image reconstruction algorithms, the spatial resolution degrading effects can be introduced in the system matrix which models the detection process. The system matrix can be factorized to introduce the blurring component in the form of blurring kernels in the image space [3].

Similarly, for motion correction reconstruction, the spatially variant and motion dependent loss of spatial resolution can be corrected in the image space. In this work we estimate the spatially variant resolution of the Siemens Inveon preclinical PET scanner and using this model we calculate a motion dependent spatially variant blurring kernel for PET motion correction reconstruction.

The proposed method is particularly aimed for scans of freely moving animals in which the animal can move over the entire scanner FOV.

II. METHODS

A. Estimation of the scanner point spread function

The preclinical PET scanner is a Siemens Inveon microPET which has crystal detector size of 1.5 mm. The transaxial FOV has a diameter of 10 cm and the axial length is 12.6 cm. The spatially variant point spread function (SVPSF) was estimated by measuring 20 point sources distributed along the radial direction and placed at the center of the axial FOV. Compared to a spatially invariant Gaussian model, the motion dependent SVPSF produced improved spatial resolution in motion corrected reconstructions of a resolution phantom. Using the motion dependent SVPSF in motion correction reconstruction improves spatial resolution and quantification in PET reconstructions. Therefore, scans of freely moving animal can benefit from using this method.
To test the parametrized SVPSF, eight glass capillaries with an inner diameter of 1.5 mm were filled with $[^{18}\text{F}]$FDG and scanned during 10 min. The long axis of the capillaries is aligned with scanner axial axis and they were evenly distributed along the radial direction. The capillaries were reconstructed using list-mode maximum likelihood expectation maximization by performing the spatial resolution modeling in the image space [3]. The data was reconstructed using the estimated SVPSF and with a spatially invariant Gaussian kernel with a FWHM of 1.2 mm for comparison.

B. Calculation of the motion dependent SVPSF

Motion correction reconstruction is calculated using list-mode motion compensation [5] without attenuation, scatter or randoms correction. Motion tracking is performed with the point source tracking method [2]. Once the scanner SVPSF has been estimated, this model is used to calculate the motion dependent SVPSF for the voxels of the motion corrected reconstructions (SVPSF-MC). We assume that the PSF of the motion corrected reconstruction voxels is a superposition of several PSF’s, which values depends on the position of the object within the scanner FOV over time. Therefore, the SVPSF-MC is calculated as follows.

Using the motion tracking data, the voxels $V_j^{ref}$ are transformed form the reference pose to which all events are transformed $P^m$, to the pose in which the events were originally detected $P^m$:

$$V_j^m = P_k^m (P^{ref})^{-1} V_j^{ref}$$

Then the spatially variant blurring kernel is calculated for the voxel $V_j^m$ using the parametrized SVPSF model. This operation is performed for all poses $K = 1, ..., k$ and the kernels are summed over all poses. Finally, the summed blurring kernel is normalized so that the sum of all its elements is 1. It is assumed that the time of every pose is the same. Otherwise, a weighed summed of the kernels needs to be performed using a weight scale proportional to the time duration of every pose $k$.

C. Moving resolution phantom experiment

To test the SVPSF-MC an experiment of a moving resolution phantom was performed. A resolution phantom with rod sizes 1.2, 1.6, 2.4, 3.2, 4.0, 4.8 mm was manually moved during a 10 min PET scan. The phantom was moved with an average speed of 2.5 cm/s during the entire scan. Four point sources were pasted on the phantom case to track its motion.

List-mode motion correction reconstruction of the phantom was performed with resolution modelling using a 1.2 mm FWHM Gaussian kernel and the calculated SVPSF-MC kernels.

III. RESULTS

A. Scanner PSF

Fig. 1a shows the reconstruction of the capillaries using the estimated SVPSF (top) and a spatially invariant Gaussian kernel (bottom). The degradation of the spatial resolution towards the edges of the FOV (increasing $r$) is visible in the capillaries placed away from the center of the FOV in the reconstruction without SVPSF. In contrast, the spatial resolution is more homogenous along the radial direction in the reconstruction using the SVPSF kernels.

The capillaries profiles along the radial direction are shown in Fig. 1b. The degradation of the spatial resolution is visible as loss of intensity in the capillaries activity, which can be observed as a maximum reduction to 45% relative to the value at the center of the FOV in the reconstruction without SVPSF. This effect is diminished using the SVPSF, with a maximum reduction to an intensity of 74%.

B. Moving resolution phantom experiment

Fig. 2 shows the motion corrected reconstruction of the resolution phantom using the SVPSF-MC and the spatially invariant Gaussian kernel. Images corrected using the SVPSF-MC present less noise than those using the Gaussian kernel.

Profiles in Fig. 2d,e show the improvement in spatial resolution using the SVPSF-MC kernel compared to using the Gaussian kernel. The maximum intensity increases about 12% and 25% for the 2.4 and 3.2 mm rods respectively using the SVPSF-MC kernel.

IV. CONCLUSIONS

We estimated and parametrized the scanner PSF in function of the radial distance to calculate the spatially variant resolution kernels. We used this model in motion corrected reconstructions to calculate the spatially variant and motion dependent PSF of motion corrected images. A capillaries phantom experiment showed the improvement in spatial resolution using the estimated PSF model. In a moving resolution phantom experiment, the motion corrected reconstructions present lower noise and improved spatial resolution using the SVPSF-MC kernels compared to the use...
of a Gaussian kernel. The proposed method helps to improve quantification accuracy in motion corrected reconstructions, e.g. used for experiments of freely moving animals in which the animal can be located anywhere inside the scanner FOV.

V. REFERENCES

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