Motion-compensated EM PET Reconstruction for Simultaneous PET/MR Exams

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Introduction: Physiological motion is one of the major sources of image-quality degradation in quantitative PET imaging. Several techniques have been presented to detect and compensate for intrinsic motion and to create motion-free PET images. When using PET/CT scanners, motion information is usually derived directly from the PET data itself because the high radiation dose caused by CT scanning makes it impossible that the patient can be monitored with CT throughout the PET acquisition. The PET data, however, can suffer from high noise levels depending on the injected tracer dose. With the availability of first clinical PET/MR scanners, it is now possible to monitor the patient activity continuously during PET exams and to use information from simultaneous MRI acquisitions to generate motion-compensated PET images. In this work, we describe a new method to extract motion information from the MR signal and to apply it for the correction of the PET scan. As opposed to previously described methods [1], the motion compensation described here is incorporated directly into the PET reconstruction algorithm, leading to improved image quality compared to techniques that apply corrections to intermediate motion-gated reconstructions. Initial results from in-vivo data are presented and demonstrate the efficiency of the technique.

Methods: Data were acquired using a clinical whole-body 3T PET/MR system (Siemens Biograph mMR) equipped with a 12-channel body matrix coil. The MRI acquisition was performed using a radial "stack-of-stars" 3D gradient-echo sequence (Radial-VIBE) with golden-angle ordering. Imaging parameters included 24 slices with 1.2 mm thickness and 6/8 partial Fourier, TR=4.46 ms, TE=1.27 ms, FA 10°, FOV 380 mm^2, base resolution 192 pixels (with 2-fold oversampling), and 2400 radial spokes. At the same time, a 5 minute PET list-mode acquisition was performed while the patient was breathing normally.

To integrate the motion compensation into the PET reconstruction, the classical line-of-response model [2] was extended by a motion component that is combined with the PET system matrix. Accordingly, the conventional Expectation Maximization (EM) algorithm

$$f^{k+1} = f^k \frac{1}{X^T 1} X^T \frac{g}{X f^k}$$

was replaced by

$$f^{k+1} = f^k \frac{1}{(XM)^T 1} (XM)^T \frac{g}{(XM) f^k},$$

where X represents the normal system matrix, f denotes the image to be reconstructed and g contains the acquired emission data. M denotes a motion operator and may include arbitrary motion information. This modification allows performing the forward and backward projections along bent lines of response [3], as illustrated in Figure 1.

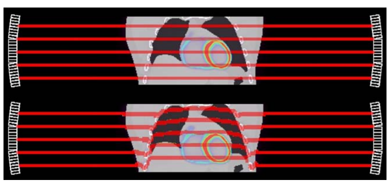

Figure 1: (Top) Classical line model for PET and (bottom) projection along bent lines according to motion vectors.

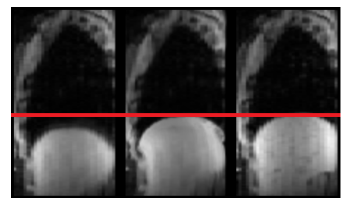

Figure 2: (Left) Gate 10 uncorrected and (middle) with motion correction, compared to (right) gate 1.

Motion information was generated using the MRI data by first extracting a respiration signal from the k-space center of the continuous radial acquisition (kx-ky-kz=0), which reflects the average signal-intensity change over the entire FOV. To obtain a robust signal, only the coil element closest to the diaphragm was used and a smoothing operation was applied to reduce noise. Afterwards, the respiration signal was used to sort the MRI data into ten respiratory states. In most cases, only incomplete data is available for some of the respiratory states. Therefore, a previously described joint multi-coil compressed-sensing reconstruction [4] with total-variation constraint along the respiratory dimension was employed, which creates a 4D image volume without undersampling artifacts that represents the 10 different respiration states. The first respiratory state was identified as the end-expiration phase and selected as reference state. All other states were then registered to the reference state using an algorithm based on optical flow [5]. The spatial transformations estimated during the registration procedures were then used to construct the motion operator *M*. Finally, the MR-derived respiration signal was used to sort and bin the PET data into ten matching respiratory states [6] and the extended EM algorithm was performed to reconstruct the motion-compensated PET images.

1	1.000000	1.000000
2	0.998752	0.998994
3	0.998656	0.998952
4	0.998472	0.998900
5	0.997085	0.998436
6	0.991846	0.997534
7	0.982399	0.995644
8	0.970555	0.992752
9	0.959741	0.989726
10	0.953324	0.987597

Table 1. Correlation coefficients between gate 1 and all other gates (middle) before correction and (right) after correction.

Results: To demonstrate the performance of motion estimation, the motion operator was applied to the MR images for all respiratory states and correlations to the reference state were calculated. Table 1 summarizes the improvement in image correlation achieved through application of the operator. For illustration purpose, Figure 2 shows images in sagittal reformatting for (right) the reference state 1 in comparison to state 10 (left) before and (middle) after applying the motion operator, which results in a uniform level of the diaphragm. Figure 3 shows in-vivo PET reconstructions from an IRB-approved patient exam, overlaid onto the MR image obtained for the reference respiratory state. Without motion compensation, as shown on the left side, the myocardial wall suffers from motion blurring and local signal-intensity losses, whereas the proposed motion-compensated reconstruction provides sharp edges and consistent intensity values.

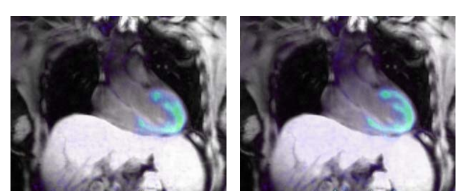

Figure 3: (Left) Reconstruction without motion correction compared to (right) reconstruction using the proposed motion correction.

Conclusions: This work describes a new approach for motion-compensated PET imaging that incorporates motion-information derived from a simultaneous MR acquisition directly into the PET reconstruction. The feasibility was demonstrated using in-vivo data and the preliminary results suggest that the proposed approach could be a promising tool to overcome motion-related image degradations seen in clinical PET exams. Further evaluations on a larger collection of datasets as well as validation of the clinical efficacy are ongoing.

References: [1] Grimm et al. MICCAI 2013 #624 [2] Shepp et al. IEEE TMI. 1982;1(2):113-122 [3] Koesters et al Fully3D 2013 [4] Feng L, et al. MRM. 2013 Early View. doi: 10.1002/mrm/24980 [5] Dawood et al. IEEE TMI 2008;27(8):1164-75. [6] Buether et al. JNM 2009, 50: 674-681.