Compensation for nonrigid motion using B-spline image registration in simultaneous MR-PET

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Introduction

Motion correction in PET imaging has been actively researched in the PET community, however obtaining accurate motion estimation is challenging. Motion has been usually estimated from CT images in PET/CT acquisition or from the PET data themselves. However, both modalities have limited accuracy for estimating motion because CT suffers from poor soft tissue contrast while PET has poor spatial resolution.

MRI tagging patterns can be used as markers which allow tracking deformations. High frequency information such as tagging patterns can improve the performance of deformation estimations in image registration [1]. We have investigated improvement to motion-corrected PET reconstruction using HARP tracking [2] in numerical simulations [3] and phantom studies. In this abstract, we report preliminary results on motion-correction in simultaneous MR-PET imaging when motion is estimated using intensity matching based B-spline image registration. A novel motion regularizer based on the topology-preserving constraint is used for the motion estimation [4]. Our results show improvement with B-spline registration over HARP motion tracking.

Methods

A. Data acquisition

A moving phantom consisted of a container filled with a viscous gel with background activity. A balloon with several radioactive spheres (10 mm diameter, different activity ratio) was suspended in the gel. The balloon was inflated at ~1sec periods using a ventilator causing the spheres to move as well. A trigger signal was generated by a pressure monitor and sent to an integrated MR-PET scanner at our center (BrainPET prototype PET scanner operating in the bore of a 3T TIM Trio scanner; Siemens, Germany).

We collected tagged MRI and PET list-mode data simultaneously. For the MRI acquisition, we used a GRE with TE = 2.41 ms, TR of 1 s, a FOV of 128x128x128 mm, and a matrix size of 128x33x32 over 3 SPAMM axes {X, Y, Z} [5]. The tagging pattern distance was 8 mm.

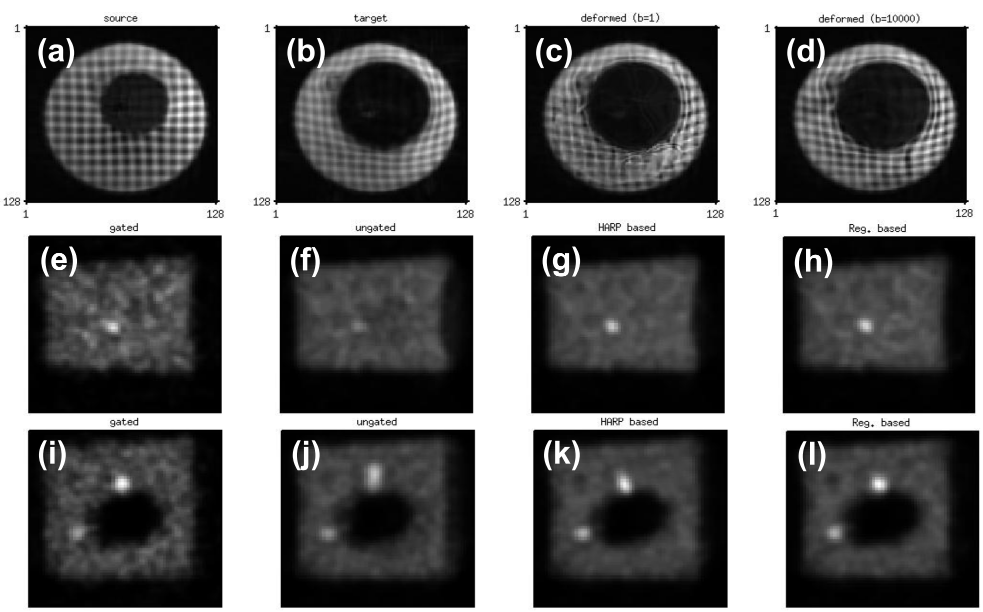
B. Motion estimation from MR images

We chose 8 phases out of the available 32 phases (8 gates for PET) and estimated motion from each phase to the first phase (reference). Cubic B-spline nonrigid motion estimation was applied to the sum of the x, y, and z direction line tagged images and the distance between adjacent B-spline control points was 4 mm in each direction. A penalty based on the sufficient condition for topology preservation encourages the local invertibility of deformations in a fast and memory-efficient way [4]. This discourages the folding of deformations and the deformed tagging patterns.

The usual choice for nonrigid image registration of tagged MRI is mutual information based registration [6] because the T_1 decay of tagged MRI changes the image intensity over time. For a constant 1D image and a global translation t, we can denote two images at different motion phases $f_1(x) = A_1 + B_1 \cos(kx)$ and $f_2(x; t) = A_2 + B_2 \cos(k(x-t))$ where A_1, A_2, B_1, B_2, k are constants. Then for a large domain for x, it is not hard to show that we can estimate a translation t which is close to a true value by minimizing the norm of the difference between $f_1(x)$ and $f_2(x)$ with respect to t. For B-spline nonrigid image registration, large support of B-spline basis and a strong regularity condition for deformations can encourage this property.

C. PET image reconstruction

We used a novel list-mode Motion-Corrected Expectation-Maximization (MC-EM) PET reconstruction algorithm developed by the authors, with estimated motion modeled in the system matrix to reconstruct the list-mode PET data while correcting it for motion. Attenuation correction maps were also deformed by the estimated motion. Reconstructed images were smoothed with a Gaussian filter with 5 mm FWHM.



Results

Figs. (a) and (b) show the source (reference) and target tagged MR images (1st and 17th phases at slice = 64 mm). Fig. (c) shows the deformed image by the estimated motion with a weak regularization parameter in which some locally broken tagging patterns were observed. However, with a strong regularization, Fig. (d) shows the deformed image that more accurately matches patterns (not intensities) of Fig. (b).

Figs. (e) and (i) are gated PET reconstructed images (using 1/8th of collected data in the reference motion phase) and Figs. (f) and (j) are un-gated reconstructed images (using all the data at all motion phases), showing spheres that are disappearing or blurred on these images. Figs. (g) and (k) are HARP-corrected PET images that show improvement in terms of SNR or motion blurring. Figs. (h) and (l) show more improvement in terms of sphere shapes using the strong regularization of Fig. (d).

Our proposed method showed significant improvement over a HARP based method in terms of contrast and SNR for large motion. For one sphere in Figs. (k) and (l), the proposed method had a contrast of 3.9 and a SNR of 20.7, while a HARP based method had a contrast of 2.4 and a SNR of 14.1. Contrast and SNR of the proposed method for PET reconstruction achieved as good a result as HARP based PET reconstruction on most spheres for smaller motion.

Discussion

Intensity matching B-spline registration based PET motion correction achieved ~60% better contrast and ~50% better SNR, compared to a HARP based correction, in spite of the tag fading due to relaxation of the tag lines. Additional investigation will help to identify and quantify the motion tracking characteristics of these techniques that most directly affect PET reconstruction in simultaneous MR-PET.

References

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