PET Restoration by Maximization of MRI-PET Mutual Information

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Purpose

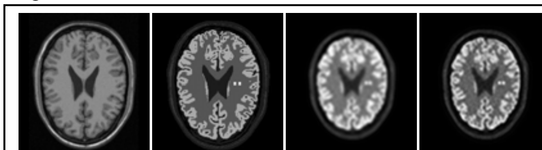
Positron Emission Tomography (PET) is an imaging modality that yields physiologic and metabolic information for clinical diagnosis based on altered tissue metabolism. PET images provide functional activity of the subjects, while Magnetic Resonance Imaging (MRI) gives the high-resolution anatomical information. Although the spatial resolution of PET images has reached to 4mm in recent commercial human scanners [1], this is still inferior to that of other tomographic imaging modalities, such as MRI and CT whose image resolution is about 0.5-1mm. The relatively low image resolution of PET might lead to inaccurate estimate of tissue tracer concentration when the size of the structure of interest is small relative to the spatial resolution. The partial volume effect (PVE) both within and across slices further degrades the image resolution and causes the difficulty in identifying small abnormal structures. Since it has become an established practice to acquire a MR data set for each patient undergoing a PET study, in this study we demonstrate the feasibility to improve the resolution and quantitative accuracy in PET by using *a priori* information from MRI. The methods are applied in clinical data sets in patients with epilepsy.

Methods

Inspired by the success of the application of maximization of mutual information (MMI) in multimodal image registration, the MMI based image restoration algorithm was proposed. The intensity values in multimodal images for the same volume of the object are not independent qualities, but statistically related measurements. The mutual information between MR images and PET images is defined as the distance between the joint distribution and the distribution associated to the case of complete independence. We applied mutual information to include the prior information from MRI into PET restoration. The basic principle is that the mutual information between the restored PET images and the MR images is maximized when the PET images are restored to the greatest degree achievable based on the available *a priori* MR information. It is valid for brain images, because PET brain images contain sufficient anatomical information, which is also contained in the MRI. In this study, Sharpness-Constrained Wiener filter was implemented to estimate the true images from the degraded PET images. MMI criterion was used to estimate the FWHM (full width half maximum) of the PSF and sharpness-constraint parameter in the restoration filter. Nelder-Mead simplex method was used to find the optimal parameters by the MMI criterion. Parzen windows method with Gaussian kernel function was applied to estimate the intensity probability density functions for MR and PET images. The Sharpness-Constrained Wiener filter was constructed based on the optimal parameters. The generated filter was applied on the PET images to obtain the PET restored images. However, MMI may fail as a restoration criterion for some human data due to the insufficient mutual information in the MR and PET images. In human studies the gradient-weighted mutual information proposed by Pluim [2] was used to combine the gradient information and mutual information for restoration.

Results

MMI based image restoration algorithm was first performed on a digital realistic brain phantom. The optimal parameters were obtained when the mutual information between PET restoration image and anatomical MR images is maximized. The optimal FWHM and sharpness-constraint value are estimated as 4.6mm and 3 $(\text{cycle/pixel})^{-1}$. The generated filter was applied on the PET images of brain phantom to obtain the PET restored images, which are shown in Figure 1. One horizontal line is drawn to cross two 4mm by 4mm rectangle hot spots with 8mm center-to-center separation and its profile is demonstrated in Figure 2. According to the line profile, two hot spots were hardly differentiated on the original PET images, however they are well separated on the restored image, indicating an improvement in resolution. Evaluation was performed using 6 quantitative criteria, including improved resolution, sharper edges, better contrast, higher SNR, small structure and lesion detectability and more accurate radioactivity concentration. The proposed method was also performed on PET images acquired from patients with epilepsy. The gradient-weighted mutual information was used to estimate the optimal FWHM and sharpness-constraint parameter. Evaluation of the original PET image quality was performed qualitatively by visual inspection using six criteria. According to each criterion, original PET images were separated into 3 groups: Excellent, Fair and Poor, and how the restoration method works in these 3 groups was investigated. Figure 3 shows PET restored images and interpolated images (to the same matrix size) from 3 different slices. Qualitative evaluation of differences between these two sets of images, presented in a randomized fashion, were performed by expert radiologists. The results showed that the PET restored images have a better contrast and sharpness than PET interpolated images. 9 out of 13 cases with excellent contrast were improved in contrast after PET restoration, while only 4 out of 9 cases with fair to poor contrast were improved. And 11 out of 14 cases with excellent sharpness were improved in sharpness after PET restoration, while only 4 out of 8 cases with fair or poor sharpness were improved. Therefore, the improvement was better especially when the original PET images were with excellent contrast and sharpness.



(a) (b) (c) (d)

Figure 1: MRI image (a), Activity image (a), PET interpolated image (c), PET restored image (d) for a digital realistic brain phantom

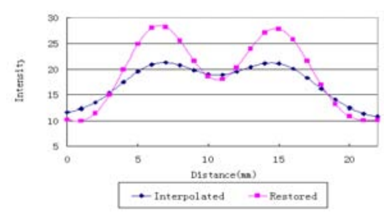


Figure 2: Line profile for the horizontal line crossing two hot spots in the PET interpolated image shown in Fig. 3(c) and the PET restored image shown in Fig. 3(d)

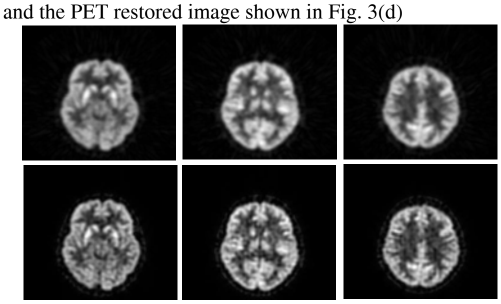


Figure 3: Axial slices, 14 (left), 17 (middle) and 20 (right), of PET interpolated images (the upper) and restored images (the bottom) for one human subject in an epilepsy study.

Discussion

In this study, the criterion of maximization of mutual information (MMI) is proposed to apply *a priori* information from high-resolution MR images on the restoration of low-resolution PET images. The basic idea is that the mutual information between multimodal images is maximized when the low resolution images are restored to the greatest degree achievable based on the available *a priori* information. Since *a priori* information from MRI is included by mutual information, prior segmentation or preprocessing in MR images is not required. Therefore, errors introduced by segmentation or preprocessing are avoided. The approach is a fully automatic method without any manual intervention and therefore highly suitable for routine clinical use. To our best knowledge, this is the first effort to introduce MMI criterion to apply the information from multimodal images for image restoration. The introduction of MMI criterion provides a new method to take advantage of *a priori* information from other image modalities. MMI criterion was implemented using the Sharpness-Constrained Wiener filter and used to estimate the FWHM of the PSF and sharpness-constraint parameter. The resulting filter was performed on the digital realistic brain phantom and human data from an epilepsy study. The improvement in brain phantom study was proven using 6 quantitative criteria, and the improvement in human data was confirmed in evaluations performed separately by two radiologists. In summary, our results demonstrate that Sharpness-Constrained Wiener filter using MRI-PET mutual information is an effective method for PET restoration. It can be easily implemented in clinical setting to improve the resolution and quantitative accuracy of PET images when the MRI is available.

References [1] John L. Humm et. al. European J. NMMI. 2003; vol. 11:1574-1597. [2] J. P. W. Pluim et. al. IEEE Trans. MI, 2000; 19:809-814.