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Reliability of using a fixed matrix in coregistration of combined PET-MRI in a split magnet design

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Abstract

We consider the effects of using a fixed linear transformation to match positron emission tomography (PET) and magnetic resonance imaging (MRI) data acquired simultaneously using a split-magnet system. Estimates of the frequency offset in MRI scans were used to calculate geometric variability in MRI reconstruction as a consequence of mis-setting this parameter in addition to repeated estimation of the transformation matrix by manual measurements. None of the measured variability approached the resolution of the PET images so we concluded that a fixed matrix can be reliably used in such a system.

Introduction

Magnetic resonance imaging (MRI) provides excellent soft-tissue contrast in in vivo imaging at a high spatial resolution. Positron emission tomography (PET) produces quantitative maps of tracer concentrations with high sensitivity though with relatively poor spatial resolution. Several efforts have been made towards combining these modalities in a single instrument, with the primary benefit of spatial colocalisation of the functional data from PET with the anatomical data of MRI.

MRI images are reconstructed by Fourier transformation of radiofrequency signals encoded with frequency and phase offsets and those of PET are obtained by filtered backprojection or iterative techniques based on detector counts in the ring surrounding the field of view. Even with data acquired simultaneously from the same physical space, therefore, the data must be transformed into the same coordinate system for subsequent use and analysis.

The present study considers whether an affine matrix, calculated to map coordinates $\mathbf{x} \in \mathbb{R}^3$ from the MRI reconstructed image to coordinates $\mathbf{x}'$ from the reconstructed PET data varies between subjects over time or can be considered as a fixed adjustment of a given imaging system. Two approaches are used, based on measurements of effects on image translation from MRI data and secondly by repeated estimation of an affine transformation matrix by manual registration of PET and MRI images acquired simultaneously. This study is based upon the Cambridge split-magnet PET MR system described previously [1-2].

Methods

Frequency offsets in MRI

In MRI acquisition, if the frequency adjustment is not correctly set, the image will be displaced. Contributions to this come from shim adjustments and sample effects, for example chemical shift effects (offsets in resonant frequency between water and fat signals). To assess the impact of this effect, we took the variability in the frequency setting of scans over time as a measure of the magnitude of potential errors in frequency as translations in the reconstructed images. Large offsets would always be noted by the scanner operator, so we excluded scans that were more than 5% off resonance. Not all of this variability will translate to actual variability in image position but we wanted to find an upper bound for the effect.

In addition, long-term drifts in frequency are due to the changes in the magnet over time rather than the outcome of an adjustment so long-term linear trends were removed from the data prior to analysis. To widen the scope of this result, we looked at all scans taken on the split-magnet PET MR console in addition to those from our busiest small-bore scanner since it was commissioned three years ago. The latter scanner operates at a field strength of 4.7T (200.3 MHz).

Repeated estimations of the linear matrix

An empirical estimate of the affine matrix was obtained in 14 separate pairs of images acquired on the PET MR scanner. These scans all used fluorine tracers ([¹⁸F]DG and [¹⁸F]EDAA). Reconstruction of a field of view $11.06 \times 11.06 \times 75.62 \text{ mm}^3$ was performed using filtered back-projection with a final voxel size of $0.87 \times 0.87 \times 0.80 \text{ mm}^3$. Default settings for all parameters were used in the manufacturer-provided software (Siemens microPET Manager). The registered scans included rats, mice and phantom scans acquired on the system with both modalities simultaneously running since installation to the time of writing.

For MRI acquisitions, a T1-weighted FLASH sequence (TR/TE 15/6ms, FOV $76.8 \times 57.6 \times 57.6 \text{ mm}^3$) was used with isotropic resolution $300 \mu\text{m}$. Images were aligned manually using SPM5 with the SPMMouse toolbox (Wellcome Trust Centre for Neuroimaging, UCL: <http://fil.ion.ucl.ac.uk>).

Results

Frequency measurements

Chronological measurements of frequency offsets are shown in Figure 1. As discussed in the introduction, only variations subject-to-subject were considered in estimating variability here. After removing first order trends in the data, the standard deviation of frequency offsets is 497.0 Hz for the 1T PET-MR system and 227.9 Hz for the 4.7T system.

For typical MRI acquisition settings with a bandwidth of 50kHz and a matrix of 256 elements, these offsets will correspond to 2.5 voxels for the 1T system and 0.9 voxels for the

4.7T system. With a voxel size of 0.2mm, these correspond to 0.45mm and 0.18mm respectively.

The difference would manifest in the frequency encoded direction or slice directions, in the latter the effect would be much less significant ($<10\mu\text{m}$ for a 1mm slice acquired with 50kHz bandwidth).

Manual matrix measurements

A typical alignment pair is shown in Figure 2. The standard deviations in parameters required to match all 14 such simultaneously-acquired image pairs were $260\mu\text{m}$, $530\mu\text{m}$ and $700\mu\text{m}$ for translations in x , y and z and 1.0° , 0.4° and 0.0° for rotations about the x , y and z axes.

There was no variability found in the adjustments to linear scaling parameters, as judged by manual inspection.

Conclusion

Repeated calculation of the matrix using different image pairs did not give a substantially different result and the maximum effect of typical frequency offsets is of the same or lower order of magnitude of the error in estimating the matrix. The method of comparing frequency variations of the MRI used here will include effects irrelevant to geometry and is an over-estimation if taken to be entirely as geometric error. Using a specific geometry matching phantom may allow automated estimation of registration parameters which would improve this study, but the existing data presented here are already adequate to suggest a fixed matrix will be sufficient in our system.

References

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Figure 1.

Frequency offsets (relative to the Larmor frequency) measured from 3 years of operation of the PET-MR system and the busiest system of the department, a 4.7T system. The large discontinuity in the latter corresponds to a magnet service, involving its field being ramped down and back up.

Figure 2. Exemplar coregistered images of MRI (grayscale) and PET (colour scale) overlaid following manual registration. This image shows a mouse following i.v. administration of ^{18}F -EDAA which binds to peripheral benzodiazepine receptors.