Non-Rigid Registration of Diffusion Weighted MRI using Progressive Principal Component Registration (PPCR)

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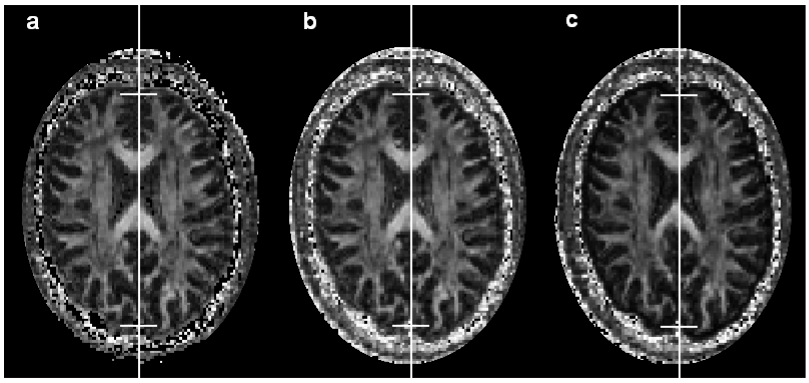
Introduction: Patient motion and eddy current distortions in the images from different diffusion directions often cause a spatial mis-alignment of Diffusion Weighted MR images, reducing the success of subsequent analysis such as tractography. These types of artefact can potentially be reduced by image registration, providing a suitable registration scheme can be found [1], [2]. An affine registration is often considered sufficient to correct the geometrical artefacts caused by eddy currents and rigid patient motion. However, features such as fibre tracks appear in multiple images with contrast dependent upon diffusion gradient direction. This changing contrast can confound standard registration techniques producing inaccurate results. Furthermore, a target image such as a non-diffusion weighted image has to be chosen. The PPCR scheme [3] used here, uses a principal components analysis to automatically generate a target image and makes use of the overlapping information in the images from different orientations to perform the registration.

Method: The PPCR [3] process is applied to 4 datasets. Each dataset consists of 64 128x128 axial slices from 15 diffusion directions using a b-value of 1000s.mm^{-2}. A multi-slice non-rigid registration is applied using PPCR and is compared to data registered using a 3D 15 degree-of-freedom affine registration (with normalised mutual information cost function) of each diffusion direction to the corresponding B0 image. A non-rigid registration can correct for both an affine transformation and also has the potential for inter-subject alignment based on fibre tracts. The PPCR algorithm performs registration repeatedly to a set of target images that have been generated from a principal component analysis of the data registered at the previous iteration. Registration between source images and artificial target images uses a fluid registration algorithm [4]. The registered diffusion data can be combined to produce a fractional anisotropy map. Feature definition can be compared between registration techniques with reference to anatomy.

Results: Figure 1 shows the results of the PPCR method applied to a single slice within one dataset. Figure 1a has been generated from the original, unregistered diffusion data. Figure 1b is the result of a single affine registration of each diffusion direction volume to the corresponding B0 volume and Figure 1c is the result of applying the multi-slice PPCR method to the diffusion direction data. Figure 1b has resulted in an unexpected increase in fractional anisotropy in the ventricles as a result of poor distortion correction. The affine registration of Figure 1b has been applied without axial corrections to eliminate through-plane interpolation artefacts due to small sub-pixel corrections. Many slices in this dataset and slices from three other datasets demonstrate that affine registration improves fractional anisotropy images compared to no correction, and the PPCR method results in improved feature resolution compared to the affine registration.



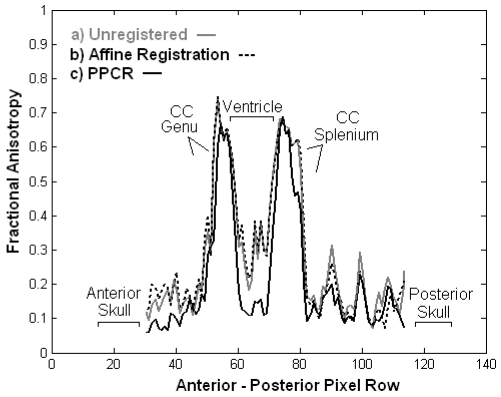


Fig 1) Demonstration of the effect of registration on fractional anisotropy maps: a) with no registration b) with affine registration of diffusion direction volumes to corresponding B0 volume and c) with PPCR registration. Note the improved resolution of features in the lateral brain regions when using the PPCR method. The adjacent graph shows a medial anterior-posterior profile through the brain, illustrating a decrease in anisotropy in the ventricles and sharper feature resolution using PPCR.

Conclusion: The PPCR method allows non-rigid registration of diffusion weighted MR images. The use of the PPCR method allows registration of different diffusion directions, with differing contrasts, into a common coordinate frame by combining overlapping image information from different orientations into early principal components. The process allows enhanced feature demarcation after further analysis (e.g. fractional anisotropy as shown and potentially tractography) by removing spatial mis-alignments. Further work will apply a full 3D PPCR algorithm.

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