Registration of Dynamic Contrast-Enhanced MRI using a Progressive Principal Component Registration (PPCR)

A. Melbourne[1], D. Atkinson[1], M. J. White[1], D. J. Collins[2], M. O. Leach[2], and D. J. Hawkes[1]

[1]Centre for Medical Image Computing, University College London, London, United Kingdom, [2]Cancer Research UK, Clinical Magnetic Resonance Research Group, The Institute of Cancer Research, Sutton, Surrey, United Kingdom

Introduction: Registration of Dynamic Contrast-Enhanced Magnetic Resonance Images (DCE-MRI) is difficult. Contrast enhancement introduces new information into images of a dynamic series so registration cost-functions that depend on information content are compromised, leading to erroneous registrations. Cost functions that seek similarity between structures in two images are confounded by the appearance of both new structure and artificial boundaries generated and enhanced by the dynamic intensity shifts induced by a contrast agent. One approach is to restrict certain types of deformation produced by the registration [1]. Using a model of pharmacokinetic uptake is a more desirable solution, but the difficulties of finding an applicable model, particularly over a wide field of view may be prohibitive [2]. We present a new data-driven model of uptake trends formed from a principal components analysis (PCA) of time-series data, circumventing the need for a physiological model. Pixels (or voxels) tracked through a time-series of images are formed by a combination of uptake trends absorbed into the results of the analysis. Careful successive registration to a combination of these trends can be used to eliminate effects that are not coherent throughout the entire time series. We term this process Progressive Principal Component Registration (PPCR). For a series of repeated breath-hold acquisitions, images are corrupted by random motion, but this motion is not a coherent trend and is likely to be given little importance in the principal components analysis when compared with long-term contrast-enhancement.

Methods: Registration is performed repeatedly to an artificial time-series of target images that have been generated using a principal components analysis of the current best-registered time-series data. PCA on a time-series of N images results in a set of N principal components. At the i^{th} repeat, only the first i principal components are used to generate the artificial target time-series, weighted by values calculated for individual pixels. The original data is registered to this artificial time-series using a fluid-equation based registration with a cross-correlation cost-function [3]. This generates registered data that has had motion removed. The PCA is re-calculated on the current registered data and a new series of artificial target images is created for the next step. The PPCR repeats adding an additional principal component at each stage. The process ends once $N-1$ principal components are included. The aim is a dataset that has had random motion artefacts eliminated but long-term contrast-enhancement implicitly preserved. The procedure is run on eight DCE-MRI datasets of the liver. Each dataset consists of a time-series of 2D coronal slices acquired at 13s intervals. The images are acquired at patient breath-hold and the patient breathes freely between acquisitions.

Results: DCE-MRI data contain significant regions demonstrating contrast enhancement. Patient movement, due to its irregular nature, is manifest largely in the less significant principal components. This makes it ideal for the registration procedure described here. Validation of the images is difficult due to the absence of a gold-standard although independent comparison with registration to the first image in the sequence by four observers shows reduced artefacts in the enhancing-region and a preference of the PPCR in 71% of cases. Structure in the images is well registered and there is no evidence of mis-registration where enhancement is present. Inspection of the first five principal components reveals a gradual reduction in the level of fluctuation with time of that component.

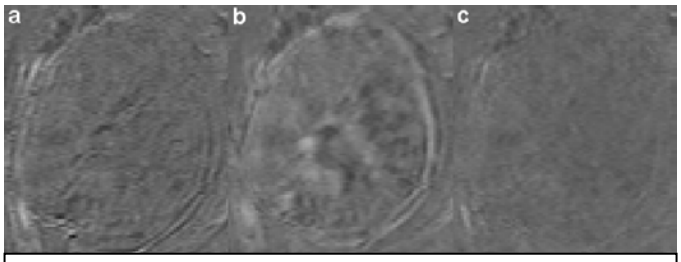

Fig 1) Subtraction of the 20th from the 32nd image in a time-series to represent mis-registration of a hepatic mass for a) No-registration b) Registration to first image in sequence (local dragging artefacts) c) PPCR to updating targets.

Conclusion: The PPCR performs well when compared to registration to a single image in the dynamic sequence. The use of principal component analysis to separate contrast-agent effects and motion artefacts causes the resulting datasets to be well registered. The method requires neither segmentation nor a pharmacokinetic uptake model but relies on contrast-enhancement to guide the registration and this is an important result in the analysis of DCE-MRI.

[1] Rohlfing, T. *et al.* Volume-preserving non-rigid registration of MR breast images using free-form deformation with an incompressibility constraint. *IEEE Trans Med Imaging,* **2003***, 22*, 730-741

[2] Buonaccorsi, G.A. *et al*. Comparison of the performance of tracer kinetic model-driven registration for dynamic contrast enhanced MRI using different models of contrast enhancement. *Acad Radiol,* **2006***, 13*, 1112-1123

[3] Crum, W.R.; Tanner, C. & Hawkes, D.J. Anisotropic multi-scale fluid registration: evaluation in magnetic resonance breast imaging. *Phys Med Biol,* **2005***, 50*, 5153-5174