Interpolation artefacts in non-rigid image registration

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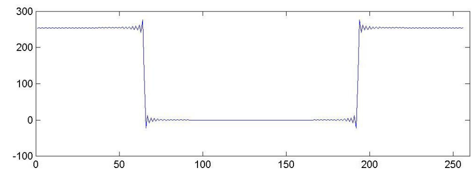
Introduction

There is growing interest in use of image registration during spatial normalisation for inter-subject comparison in neuroscience and in other research areas. In deformation based morphometry high dimensional non-rigid registration algorithms are used to bring images into detailed spatial correspondence. The resulting deformations are then analysed, for example by calculating Jacobians and using these to assess localised volume changes. We have observed that, when matching brain images, the Jacobian determinant maps can display traces of the edge structure in the underlying anatomy. This may reflect genuine differences between subjects, but could potentially be artefactual. To investigate the latter possibility we have conducted experiments using simplified synthetic images with isolated edge content.

Method

Synthetic images were created with two opposite steps located half a field of view (FoV) apart. The images initially contained two intensity levels, 0 and 255 and consisted of 256 pixels; the steps were placed either at pixels 0 and 128 (image A_{256}) or at 64 and 192 (image $B_{256,}$ profile illustrated).



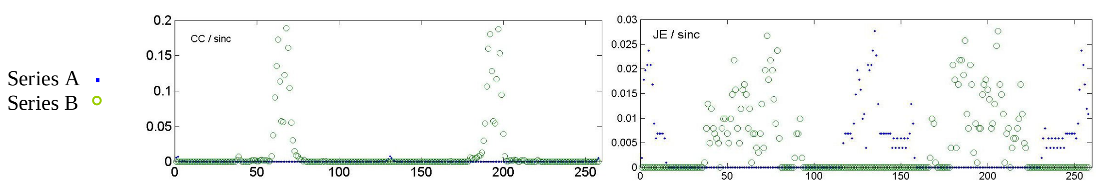
To replicate MRI data these binary images were band limited. This was achieved by expanding each pixel to 1000 sub-pixels, applying a Fourier transform and truncating the resulting series to its central 256 points before transforming back to the image domain. The band limited images were then resampled by re-applying a Fourier transform, the resulting k-space data was expanded to 258 points by addition of a zero data value at each end. On transformation back to the image domain this yielded images with the edge content at the same locations in the same FoV, but with 258 pixels (Images A_{258} and B_{258}). Note that the edges in A_{256} and A_{258} are centred on identical pixel positions, whereas the edges in B_{258} and B_{256} have local pixel grids offset by approximately half a pixel. During all subsequent processing the images were spatially replicated to avoid edge effects.

The 256 pixel images were registered to the corresponding 258 pixel images using a non-rigid registration algorithm[1]. A variety of similarity measures were tested: Cross-Correlation, Sums of Squared Differences, Joint Entropy, Mutual Information, Normalised Mutual Information (CC, SSD, JE, MI and NMI). These were combined with different interpolation algorithms: B-spline (kernel = 4 pixels), C-spline (kernel = 4 pixels), linear, sinc (kernel = 13 pixels) and nearest neighbour.

In each case maps of the magnitude of local displacement and the Jacobian determinant were calculated. In addition, the transformation resulting from the registration, along with the chosen interpolation scheme, was used to transform the 256 pixel images onto 258 pixels. Subtraction of the original 258 pixel images then allowed localised residual signals to be determined. For comparison the 256 images were also reformatted to 258 pixels using the interpolation methods alone.

Results

Image series A showed very low errors as expected. However, the information theoretic based similarity measures did introduce slight distortions (<5% pixel deformation, see graphs below). In image series B, although edges were precisely aligned by construction, and all that was required of the algorithm was to interpolate, local distortions were introduced in all cases. These distortions mostly appeared to compensate for localised interpolation errors, reducing the residual at the price of localised deformation and consequent volume change. There was an interaction between the similarity measure used and the interpolation method. The CC and SSD measures produced the most focal volume change and achieved the lowest average residual values for all interpolation methods. However, the information theoretic methods, JE and NMI tended to produce volume changes across a broader range of pixels that were smaller in magnitude by approximately a factor of 4. MI was intermediate both in the size of the Jacobian change and of the residual. For these isolated edge images, simple nearest neighbour interpolation could produce very small residuals with the CC and SSD measures, but performed badly with the information theoretic measures. Sinc was slightly better than B-spline interpolation and both gave the most robust results for Jacobian errors and residual signal. Linear interpolation was worst except for one case of nearest neighbour interpolation. In this test, CC combined with sinc interpolation resulted in lowest errors closely followed by JE combined with sinc interpolation. For sinc interpolation, the maximum intrinsic intensity error was 10, which was reduced to 1 using the CC measure through the introduction of a local 10% volume change. By contrast, the maximum residual signal was 7 with a local volume change of 2% when JE was used with sinc interpolation. As an illustration, graphs of deformation against position for sinc interpolation when used with CC and JE are shown below, deformation is measured in fractions of a pixel.



Discussion

As image structure is brought into spatial correspondence, high dimensional registration algorithms have the freedom to introduce local spatial distortion to compensate for signal errors introduced by interpolation. The degree of volume change and the signal errors remaining uncompensated depend upon the combination of similarity measure and interpolation scheme used and both of these presumably interact with the underlying anatomical structure. An additional factor is likely to be the choice of control points used in the non-rigid registration. The present study serves to highlight and illustrate the potential problems and may provide a test bed with which to evaluate developments designed to combat these effects.

References: 1. D. Rueckert, L. I. Sonoda, C. Hayes, D. L. G. Hill, M. O. Leach, and D. J. Hawkes, “Non-rigid registration using free-form deformations: Application to breast MR images,” *IEEE Transactions on Medical Imaging*, vol. 18, no. 8, pp. 712–721, August 1999.