Positional normalization as a first step in processing magnetic resonance brain images: work in progress

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***Abstract*—Retrospective automatic analysis of MR head images acquired in multicentre studies is often hampered by large differences in the positioning of the head within the image grid. To address this problem, we developed *posnorm*, a tool for preprocessing that normalizes the head position, utilizing only information contained within the image itself. Visual analysis of 21 test images from varied sources acquired with diverse protocols indicates that the procedure yields accurate and robust results. We envisage using *posnorm* routinely pending resolution of minor problems.**

I. Introduction

Neuroscientific study of human subjects is greatly facilitated by magnetic resonance (MR) imaging of the brain. Traditionally, brain images are analyzed by a trained expert, but visual review does not scale well to large studies. Yet, more and more multicentre trials on many subjects are being conducted to investigate neurological disease with adequate statistical power (e.g. ADNI [1]). In accordance with this development, the demand for automatic image analysis tools for objective evaluation of imaged cohorts is increasing.

Structural T1-weighted three-dimensional cranial MR images are acquired in almost all such studies, because images of this type provide ample information (high spatial resolution, strong soft-tissue contrast) within reasonable scanning time. Less consistently, other sequences are also acquired, with T2-weighted images being second most common.

Image registration algorithms for T1 images in particular are highly developed. These algorithms facilitate quantitative comparisons between subjects and enable, e.g., anatomical segmentation and brain morphometry [2]. However, they have traditionally been tested on homogeneous datasets acquired at a single centre on one particular MR scanner, meaning that most assume a minimum level of global alignment between any given image pair. This assumption is frequently violated for data sets of multicentre provenance, as customs regarding subject positioning and data representation can vary substantially between acquisition sites. To compensate, images often need to be manipulated interactively to roughly pre-align pairs before an automatic registration algorithm can calculate the detailed alignment parameters.

To obviate the need for time-consuming, interactive image manipulation, we propose *posnorm*, an automatic procedure that achieves positional normalization of a T1-weighted MR head image based on autochthonous information, ie. without any reference to external data. It is intended as an initial step before further processing that may involve other images, such as spatial normalization templates or reference images of individual subjects.

We applied the procedure to 21 MR images of varied provenance and assessed the results visually.

II. Material and Method

A. Algorithm

Software tools used in this research were taken from the Image Registration Toolkit (IRTK, http://www.doc.imperial.ac.uk/~dr/software) and the fMRIB Software Library (FSL, http://www.fmrib.ox.ac.uk/fsl/). The processing pipeline was implemented as a set of shell (Bash) scripts.

Positional normalization is achieved in two stages. Both involve the calulation of a rigid transformation. The first stage allows only translations, the second additionally enables rotations.

To prepare for the first stage, the field of view (FOV) corresponding to the brain is determined (FSL robustfov). In the original image, all voxels not contained in the FOV are set to zero. Subsequently, the translation is determined that moves the centre of gravity to the grid centre.

In the second, a transformation is calculated that aligns the midsagittal plane with the image grid. The centered image is preprocessed (subsampling to 2 mm isotropic resolution, blurring with a Gaussian kernel of 2 mm width) and flipped around the left-right axis. The resulting mirror image is used as the target for rigid registration (IRTK rreg), with the unflipped centered image as the source, using the default settings of the tool (iterative refinement using three resolution steps, maximizing normalized mutual information [3] between source and target). The resulting transformation is bisected (IRTK bisect_dof) to obtain the transformation that aligns the midsagittal plane with the grid.

The two resulting transformations are concatenated to obtain the final transformation that moves the original image to the normalized position.

B. Testing

To test the effect of applying *posnorm*, we devised a visual review protocol. We identified six anatomical landmarks that are commonly considered to be normally located in the midsagittal plane [4], [5], [6]: the interthalamic adhesion, a small area of contact between the left and right thalamus; the Sylvian aqueduct, which connects the third and fourth ventricles; the septum pellucidum, a soft-tissue membrane that separates the right from the left lateral ventricle; and the most superior, inferior and posterior points within the superior sagittal sinus, a blood vessel that collects venous outflow from the brain. For each of these landmarks, their sagittal distance from the centre plane was noted.

Twenty-one MR images (19 T1-weighted, 2 T2-weighted) acquired on 10 different scanners and at two different field strengths (1.5 T and 3 T) were subjected to *posnorm* processing. Original images were resliced after applying the output transformation and reviewed in comparison with the original uncorrected image using IRTK *rview*. The three sections displayed were centered on the interthalamic adhesion. Subsequently, the other five landmarks were located and their sagittal distance from the interthalamic adhesion recorded. The positional normalization was considered successful if all landmarks were found within 3 mm of the plane through the interthalamic adhesion, and none of their distances were increased in comparison with the original image.

III. Results

A. Runtime behaviour

Processing of each image occupied a single core on a standard CPU (Xeon 5150, 2.66 GHz, Intel Corp., Santa Clara, CA, USA) for 17 ± 2 seconds.

B. Visual analysis results

In 20 of 21 images, all anatomical landmarks were found within 3 mm of the interthalamic adhesion after reslicing. In none of the images tested, the normalized position was worse than the original position with regard to the landmarks. In one of the T1-weighted images (Fig. 1), the occipital part of the superior sagittal sinus was displaced 10 mm to the left of the interthalamic adhesion due to an unusual amount of asymmetry. The normalization transformation was nevertheless plausible.

Fig. 2 shows superimpositions of all T1-weighted images before and after normalization. In addition to *posnorm* processing, the images were intensity-normalized to produce the figure.

IV. Limitations

The proposed procedure relies on the *robustfov* tool provided with the recently released version 5 of FSL. This tool is designed to normalize the FOV in the inferior-superior direction. It makes an assumption about the input image containing background noise in the extracranial portions that is violated for images that have undergone certain preprocessing steps (face removal for anonymization or extracranial noise suppression). We aim to make *posnorm* applicable to such images and are working with the FSL developers to resolve the remaining problems.

The proposed procedure relies on left-right symmetry of the head image. If a target image contains strong asymmetry due to an extremely unusual configuration or very severe pathology (for example due to stroke, tumour, trauma), the results may be implausible. In practice, despite having worked with hundreds of images of traumatic brain injury, we have not seen such a failure yet.

In future work, we will also seek to normalize for rotation around the sagittal axis (the rotation corresponding to nodding the head).

V. Conclusion

Posnorm is a tool for positional normalization of MR images of the head. It is intended for integration into automated image processing pipelines in order to increase their robustness towards large differences in head positioning between different acquisitions. Initial results yield proof-of-principle and indicate promise of the method in the retrospective analysis of heterogeneously imaged cohorts.

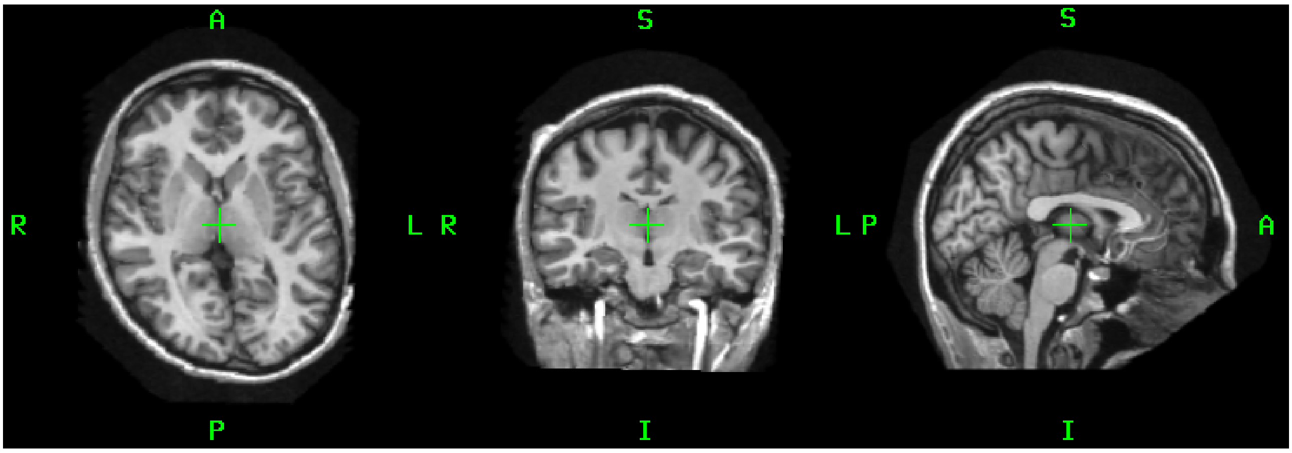

Fig. 1. T1-weighted MR head image showing unusual occipital asymmetry

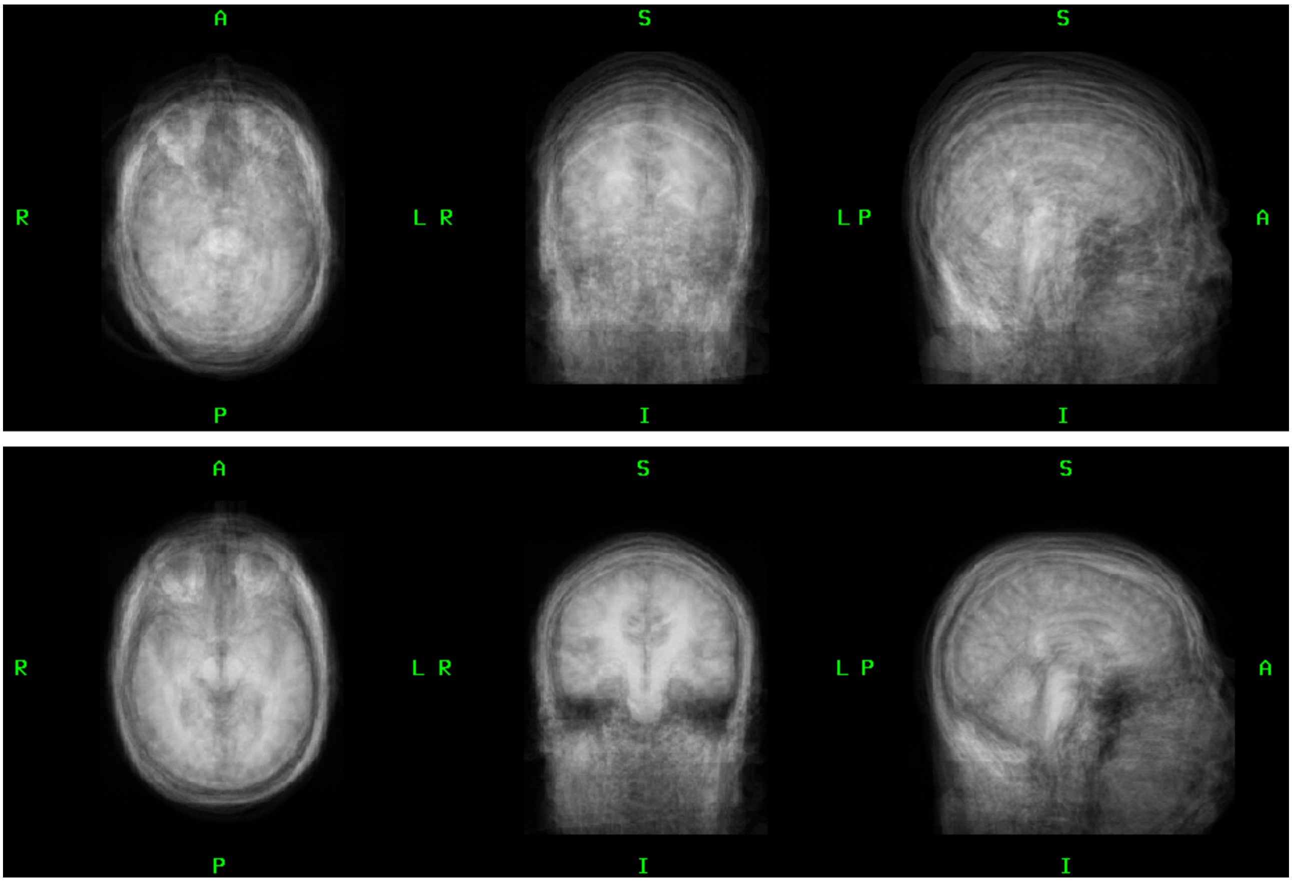

Fig. 2. T1-weighted images (n=19) superimposed before (top) and after (bottom) positional normalization

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