Inverse interpolation algorithm for retrospective motion correction in interleaved images

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Introduction

Spatially interleaved image acquisition is used in magnetic resonance (MR) imaging to minimize crosstalk between neighboring slices without introducing slice gaps. It can also be necessary to cover large volumes when acquiring images with repetition times (T_R) too short to allow data from all slices to be collected in a single pass.

Movement of the subject is particularly a problem in the very young, the very old and the elderly suffering from neurodegenerative conditions. Motion artifact within a pass is not recoverable post reconstruction, whereas motion across passes leads to misalignment of the images in the separate passes relative to each other. This, in turn, causes characteristic artifacts in the resulting three-dimensional (3D) image stacks (see Fig 1(a)), which makes these stacks unsuitable for 3D image processing (e.g., registration, multi-spectral image segmentation).

We introduce in this work a method for retrospective correction of such pass-to-pass motion artifacts. The technique first uses image-to-image registration to recover the parameters of subject motion, followed by an image reconstruction stage in which the final, artifact-corrected image is generated. The reconstruction is based on an inverse interpolation formalism, which is solved using a gradient descent minimization of the approximation error.

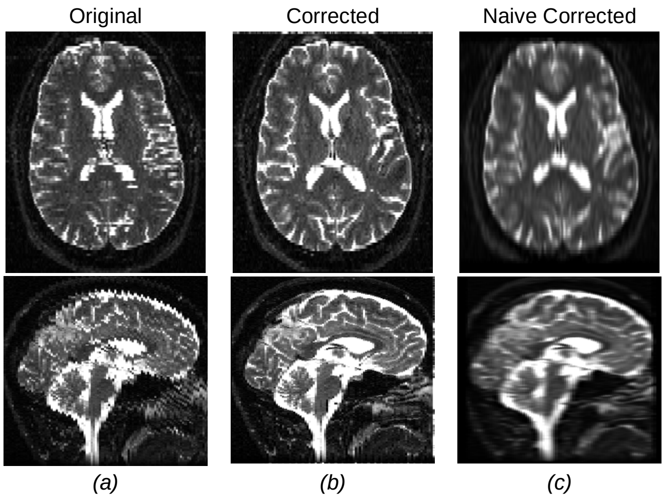

Fig 1: Example of interleaved motion artifact correction applied to late-echo FSE image. (a) Original FSE image, 3 passes interleaved in A/P direction (acquired in coronal orientation), showing characteristic motion artifacts. (b) Artifact-corrected image using inverse interpolation based on co-registered single-pass image stacks. (c) Naive artifact-corrected image using simple averaging of upsampled, co-registered single-pass image stacks.

Methods

Motion Recovery by Image Registration

The images acquired in the different passes are first combined into separate, contiguous 3D image stacks (rather than a single, interleaved high-resolution stack). To recover the motion between the passes, one of them (for example the first) is selected as the reference, and the images from the remaining passes are registered to the reference pass image using an established intensity-based 3D rigid registration algorithm based on optimization of normalized mutual information [1].

Volume Reconstruction by Inverse Interpolation

We cast the actual image reconstruction of the interleaved 3D image stack from the co-registered passes as an inverse interpolation problem. Ignoring the spatial arrangement of its pixels, we can denote the (unknown) ground truth image as a vector of pixel values, $\vec{f}$. The images from the separate passes, denoted $\vec{u}_i$ where i is the index of the pass, are modeled as having been interpolated from $\vec{f}$. Each such interpolation can be written as a matrix-vector multiplication $\vec{u}_i = \mathbf{W}_i \vec{f}$, where $\mathbf{W}_i$ is the matrix of interpolation coefficients for the i-th pass. The matrix elements of each $\mathbf{W}_i$ are determined by a) the spatial arrangements of the pixels in the images, b) the coordinate transformations between the images, and c) the interpolation kernel (e.g., linear, cubic, sinc). Now if $\vec{v}$ is an approximation of $\vec{f}$, then the least-squares approximation error can be written as

$$E = \sum_i \left\| \vec{u}_i - \mathbf{W}_i \vec{v} \right\|_2 .$$

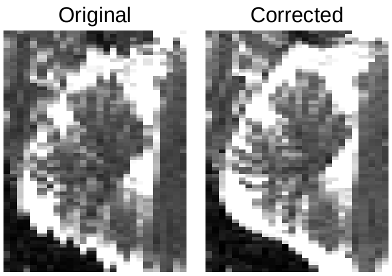

Fig 2: Enlargement of sagittal slice from Fig. 1, showing the cerebellum before (left) and after (right) motion correction.

The gradient of E with respect to the elements of $\vec{v}$ (i.e., the pixel intensities in the evolving approximation of the true image) is computed analytically, and E is minimized using a multi-resolution search strategy. Note that E is nonnegative, and zero if and only if the acquired images from all passes interpolate perfectly from the approximated true image, i.e., when $\vec{u}_i \equiv \mathbf{W}_i \vec{v}$ for all i.

Results

The effectiveness of the proposed correction algorithm is illustrated for a 3-pass coronal acquisition in Fig 1(b). Note the substantial anatomical detail recovered, for example, in the cerebellum (Fig 2). Note also the clearly visible improvement over the naive correction approach of upsampling and averaging the co-registered interleaved images, the result of which is shown in Fig. 1(c). The results shown in this abstract were computed using a cubic interpolation kernel, which provides a good trade-off between accuracy and computational performance (about 15 min computation time using 8 CPUs for a 256x256x94 pixel image).

Conclusion

We have introduced a novel, highly effective algorithm for correction of across-pass motion artifacts in interleaved images. Our method is based on true 3D motion estimation and volume reconstruction and is, therefore, able to correct post-acquisition artifacts caused by full 3D motion including rotations and out-of-plane translations.

Acknowledgments

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References

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