An Example-based Approach for High-Resolution Reconstruction of Developing Brain MRI

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Imaging moving subjects in early brain development studies remains an open issue for Magnetic Resonance Imaging (MRI). Although the development of ultrafast 2D acquisition sequences has led to significant improvements for clinical studies, the slice acquisition time is still critical and has to be as short as possible to reduce the impact of the motion. As a result, sets of thick 2D slices are generally acquired in clinical studies and interpretation remains limited by visual inspection. Rousseau *et al.* in [4] have proposed a registration-based method to compound multiple orthogonal sets of 2D fetal MRI slices into a single isotropic high resolution volume. Jiang *et al.* in [2] have proposed a very similar algorithm for volume reconstruction using B-spline interpolation. Recently, Kim *et al.* in [3] have proposed a new approach to register such stacks of slices.

In this work, we focus on the final image reconstruction step by combining low resolution images to produce an image that has a higher spatial resolution than the original images (so called super-resolution (SR) principle). For such inverse problem, some form of regularization plays a crucial role and must be included in the cost function to constrain the space of solutions. The high resolution (HR) image is computed by considering the following equation: $\hat{\mathbf{x}} = \arg\min_{\mathbf{x}} \mathcal{L}(\mathbf{x}, \mathbf{y}, H) + \lambda \mathcal{R}(\mathbf{x})$ where $\mathcal{L}(\mathbf{x}, \mathbf{y}, H)$ is a data term related to the physical model and $\mathcal{R}(\mathbf{x})$ is a regularization term.

Proposed Approach

We propose to use a patch-based approach to define the regularization term in order to take into account complex spatial interactions in images. Moreover, in contrast to recent example-based approaches for image modeling, the proposed method is unsupervised and thus uses no image patch learning database and no computational intensive training algorithms. The key idea of the proposed approach consists in saying that 2D slices of LR images contain relevant examples of the HR image reconstruction and thus the set of LR images can be considered as a relevant candidate to be the learning database $\mathcal{E}$. The proposed regularization term is defined as follows: $\mathcal{R}(\mathbf{x}, \mathcal{E}) = \sum_{\mathbf{v}} w_{\mathcal{R}}(\mathbf{v}) \|\mathbf{x}(\mathbf{v}) - d_{NLM}(\mathbf{x}(\mathbf{v}), \mathcal{E})\|^2$ where $w_{\mathcal{R}}(\mathbf{v})$ is a local weight between data term $\mathcal{L}$ and regularization term $\mathcal{R}$, $d_{NLM}(\mathbf{x})$ is a denoised version of $\mathbf{x}$ (obtained with non local means algorithm [1]), estimated using similarities between LR images $\mathbf{y}_r$ and HR image $\mathbf{x}$. The use of a non-local approach to define the regularization term has the advantage over the PDE approach to handle in a better way repetitive structures and texture.

We applied the algorithm to MR scans of healthy infants: T2 weighted Fast Spin-Echo sequence (TE/TR = 120/5500 ms) on a 1.5T MRI system (Signa LX, GEMS, USA), resolution : $0.8 \times 0.8 \times 2$mm. Figure 1 shows one original low resolution image compared to the high resolution reconstructed images for axial, coronal, sagittal views. Figure 1 shows the quality improvement providing by the proposed method compared to the local interpolation method [4].

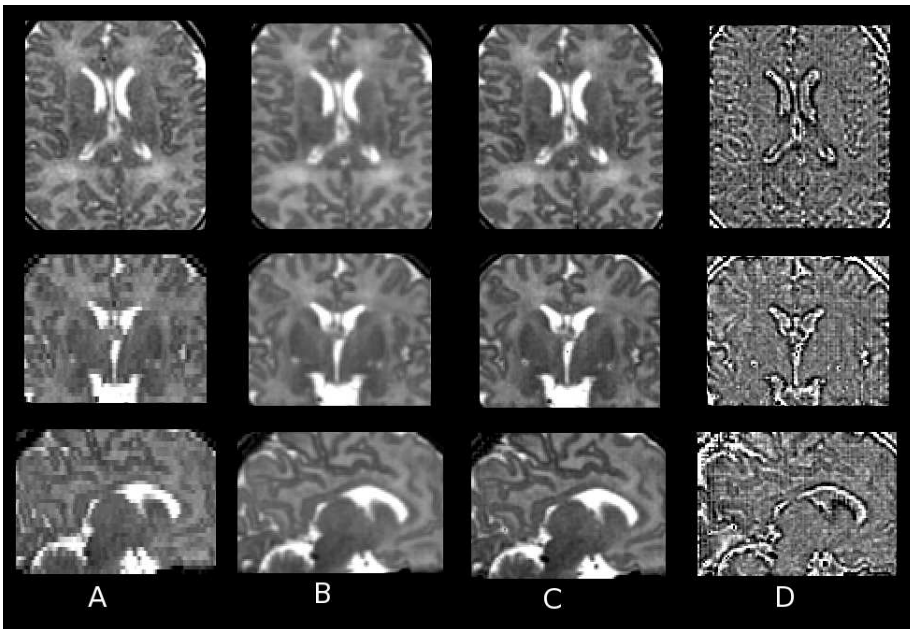

Fig. 1. Details of reconstructed infant MR images. From left to right: A) original LR, B) reconstructed image using [4], C) proposed approach, D) difference between C and B.

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