High Order Slice Interpolation for Medical Images

Antal Horváth[1], Simon Pezold[1], Matthias Weigel[1,2], Katrin Parmar[3], Philippe Cattin[1]

[1]Department of Biomedical Engineering, University of Basel, Switzerland
[2]Radiological Physics, University Hospital Basel, Switzerland
[3]Department of Neurology, University Hospital Basel, Switzerland

University of Basel

Department of Biomedical Engineering

Introduction

Medical images often have anisotropic resolution. For many applications, reslicing or upsampling are standard preprocessing steps. When dealing with images where objects have different locations between subsequent slices, naive intensity interpolations fail, as demonstrated in Fig. 1.

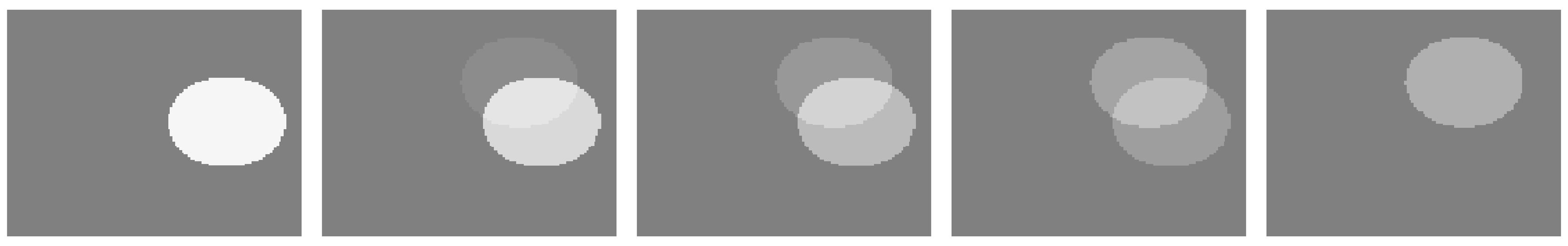

Fig. 1: Linear intensity interpolation between the *left* and *right* image.

Registration-based slice interpolation is necessary to address this problem and to create correspondences, where the interpolation takes place in between. More realistic interpolations between the left and the right image are shown in Fig. 2.

Fig. 2: Proposed intensity interpolation between the *left* and *right* image.

We propose a new slice interpolation framework, that spline interpolates the displacement fields along the interpolating axis, and the intensities along the interpolated displacement fields.

Interpolation Model

Given a stack of P similar 2D images $(I_k)_{k=1,\dots,P}$ in $\mathbb{R}^{M\times N}$, an image distance $\mathcal{D}$, and a displacement field regularization $\mathcal{R}$, we minimize the summed up registration energies of all the subsequent image pairs at specific registration evaluation points $\mathcal{S}$ along the z-axis and optimize for displacement fields $\mathbf{v}_k$ and Hermite interpolation polynomials $p_k(s,\mathbf{x})$, $\mathbf{x}\in\mathbb{R}^2$ [2], where $\overrightarrow{p_k}$ and $\overleftarrow{p_k}$ are the corresponding image domain transformations:

$$\underset{(\mathbf{v}_k:\Omega\to\mathbb{R}^2)_{k=1}^{P-1}}{\operatorname{argmin}} \sum_{k=1}^{P-1}\sum_{s\in\mathcal{S}} \mathcal{D}\left[I_k\circ\overrightarrow{p_k}(s), I_{k+1}\circ\overleftarrow{p_k}(1-s)\right] + \lambda\mathcal{R}(\mathbf{v}_k).$$

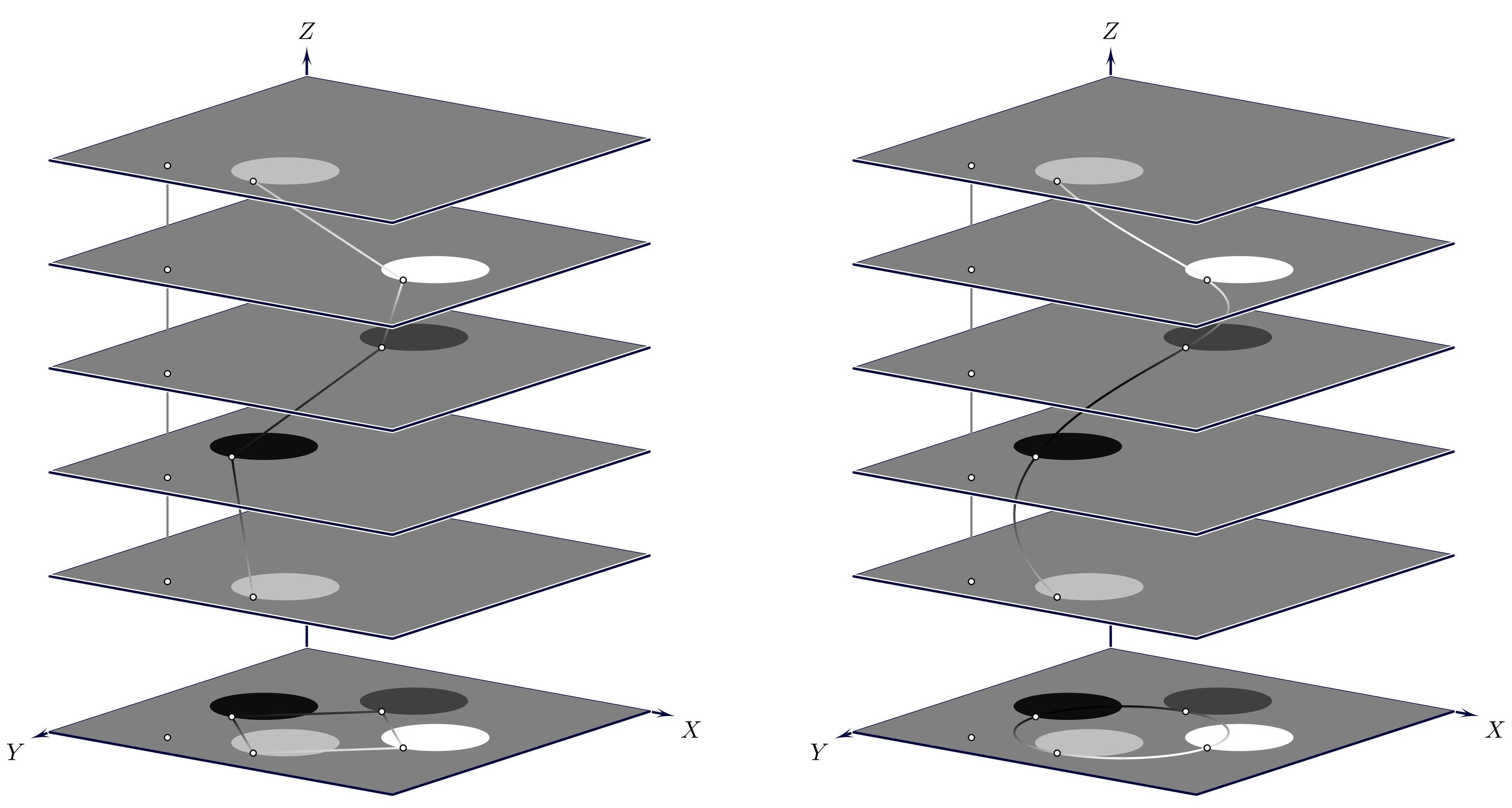

Fig. 3: Registration-based slice interpolation schemes.

In Fig. 3 two registration-based interpolation schemes are shown: piecewise linear *(left)* and smooth *(right)*, with their projections on the x-y-planes *(bottom)*. In both interpolation schemes, two exemplary correspondence curves are shown: correspondences of points in a flat region and correspondences of a boundary pixel of the circling ellipse. To get a full interpolation, such correspondence curves are established for all pixels. The proposed method [3] optimizes over the whole z range for a smooth interpolation, similar as in the right scheme.

Results

We applied the registration-based piecewise linear [1] (Fig. 4, left) and the proposed interpolation scheme [3] (Fig. 4, right) on a stack of 2D MR images. In the sagittal and coronal cuts on the left, kinks along the stitching positions are visible (yellow marks). The proposed result is smooth but not blurred.

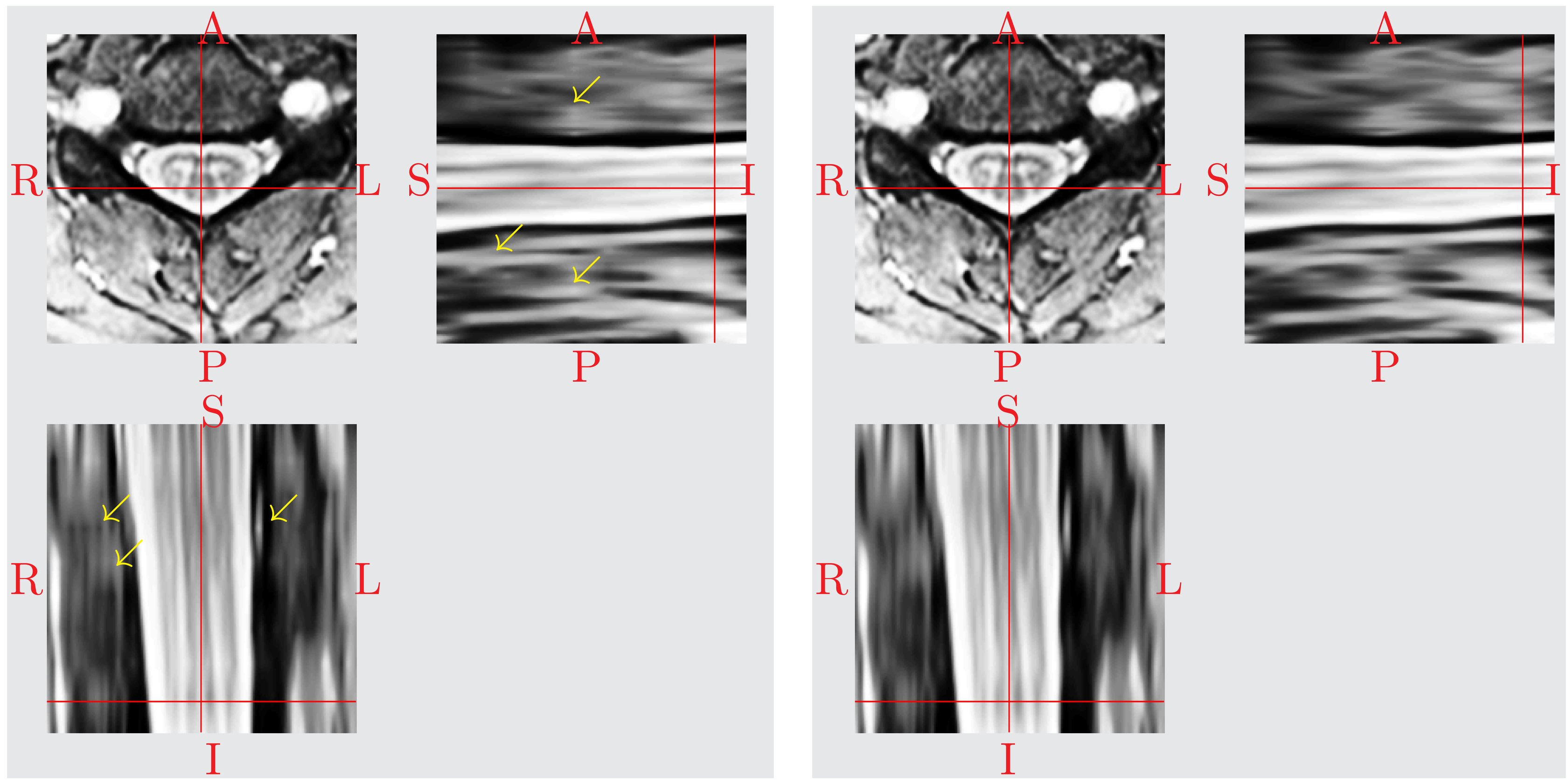

Fig. 4: Slice interpolated MRI, piecewise linear (left), proposed (right).

The proposed method not only has qualitative, visual improvements, but also quantitatively the slice interpolation capability improved, which we tested with leave-one-slice out experiments, Fig. 5.

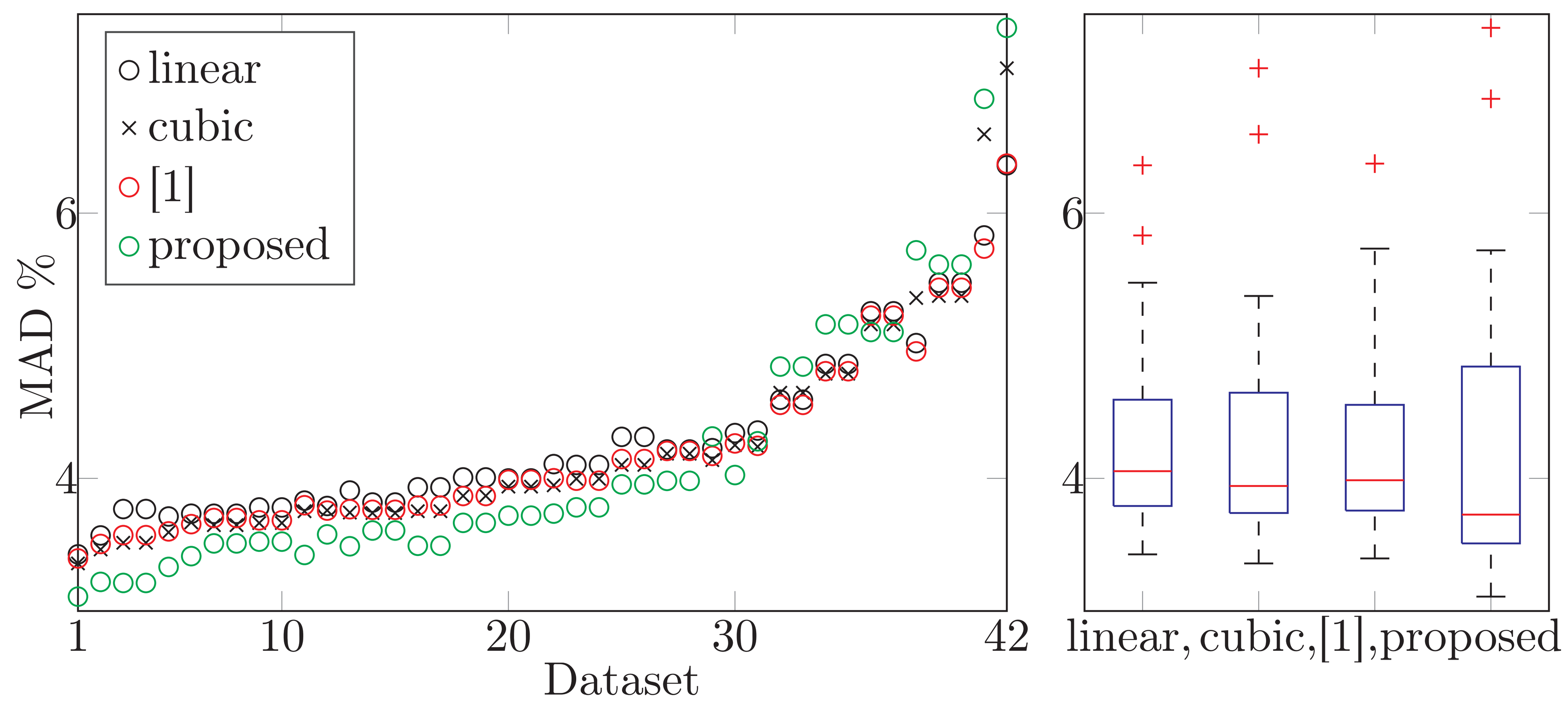

Fig. 5: Leave-one-slice-out tests with 42 datasets in $[0,1]^{120\times120\times10}$.

The mean absolute intensity differences (MAD) between the interpolated slices and the corresponding left-out slices is lower in most cases with the proposed method. The interpolation result strongly depends on the found correspondences. By choosing a more advanced image measure $\mathcal{D}$ or regularization $\mathcal{R}$ one might achieve even better results.

Contribution

- combined object and intensity interpolation
- C^2-smooth slice interpolation
- registration-based slice interpolation framework for arbitrary image distance $\mathcal{D}$ and registration regularization $\mathcal{R}$
- mathworks.com/matlabcentral/fileexchange/63907

References

[1] Baghaie *et al.* An Optimization Method For Slice Interpolation Of Medical Images, arXiv:1402.0936, 2014
[2] Hairer *et al.* Introduction à l'Analyse Numérique, http://www.unige.ch/~hairer/poly/poly.pdf, 2005
[3] Horváth *et al.* High Order Slice Interpolation for Medical Images, MICCAI SASHIMI 2017 (in press)