Partial voluming correction using reverse diffusion

O. Salvado[1], C. Hillenbrand[2], S. Zhang[2], D. Wilson[1]

[1]Biomedical Engineering, Case Western Reserve University, Cleveland, Ohio, United States, [2]Radiology, University Hospitals of Cleveland, Cleveland, Ohio, United States

Introduction: One limitation of MRI is the partial volume effect where the boundary between two structures of interest falls in the middle of a voxel and the signal is "averaged" over a sample volume. Partial volume produces significant blurring, especially when thick MRI slices are used. When the point spread function of the acquisition chain is smaller than a voxel, as it is often the case in MRI, partial voluming account for most of the limitation in resolution and the filtering of tissue boundaries. We propose a method to reduce partial voluming by restoring the ideal boundary. We assume as a first approximation that a voxel averages over a rectangular solid, and we split a voxel into sub-voxels and reapportion the signal to them. The method is based on a numerical implementation of reverse diffusion, and it shows significant quality improvement over conventionally interpolated MR images.

Methods: We start with a 2D MRI image and create sub-voxels using nearest neighbor interpolation. The gray level of each sub-voxel is considered as "material" able to move between sub-voxels but not between voxels. A partial differential equation is written to allow the material to flow towards the highest gradient direction, eventually reducing to the diffusion or heat conduction equation with a positive sign (hence the name: reverse diffusion). Special constraints keep the implementation stable by limiting the flow of material leaving a sub-voxel. Firstly, the flow is limited by the amount of signal in excess with respect to its lowest nearest neighbor. Secondly, the recipient sub-voxel of the flow should be able to receive new materials without exceeding the level of its highest neighbors. Thirdly, the amount of material in a voxel computed as the sum over all its sub-pixels is kept constant. As a result, the signal in each pixel is reapportioned among its sub-pixels to correct for partial volume effect.

Results: The method performs well as determined from synthetic images as well as actual MRI scans of both phantom and actual human acquisitions. Synthetic images were down-sampled to simulate partial volume artifact and restored. Corrected images were remarkably closer to the original images than those obtained from common interpolation methods. The mean square difference error was much reduced on multi-class test images: 6.5%, 5.9%, and 1.1% for bilinear interpolation, bicubic Interpolation, and reverse diffusion respectively (not shown). Result of actual MRI scans showed improvement of the depicted anatomy on brain and neck acquisitions. On specially design physical MRI phantoms, images processed with the new method had much crisper, truer edges than did images processed with bicubic interpolation.

Discussion: Whether MR images are observed by radiologist or used in automatic algorithms, a common pre-processing step is to interpolate the data to remove pixelization effect in the former case, and increase accuracy on the latter. The theoretically optimal method uses a sinc kernel but is impossible to implement because of the infinite support of the kernel. Numerous approximations have been proposed Lanczos, splines, bicubic, linear that allow controlling the trade-off between blurring and ringing artifact. Those methods use only the gray-level information and no assumption about the partial volume process. Moreover because of the constraint on the global flow, the signal integral is conserved. That is, when a structure volume needs to be measured, the sum of the voxel signal will not be biased as we show it is the case with other common interpolation techniques. A very desirable feature when size of tumor lesion are quantified or brain volumetric study are performed for example. In some application when partial volume effect must be corrected, especially for tissue classification application, another class of methods relies on the modeling of the image histogram, often as a Gaussian mixture, and they use spatial information between pixels to estimate the mix inside each pixel of the different classes. Almost all of them assume that a pixel can only be made of two different classes [1]. Such methods provide very good result if the assumption of multi-class images holds. Their performance is dependant on the accuracy of the histogram modeling, and some application specific parameters need to be specified such as the number of class. The method that we present does not rely on classification and histogram modeling. It uses the gray-level information of the pixels and the assumption that a partial volume blurring has occurred. It leads to better results than pure interpolation methods since it uses more information, while avoiding the drawbacks of the pattern recognition techniques. \

[1] K. Van Leemput, et al *TMI*, 22(1), 105-119, (2003).

Figure 1: The original phantom image (a) is corrected with bicubic interpolation (b) and the proposed method (c). The line profile of panel (a) is displayed on panel (d). One can appreciate the sharpness of the edges with our method compared with classic interpolation.

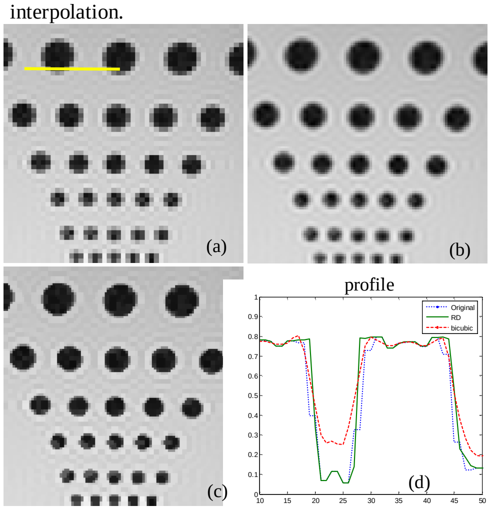

Figure 2: physical phantom acquisition (a) and its correction with the proposed method increasing the resolution by x2 (b) and x4 (c). Panel (d) shows the same initial data interpolated four times with bicubic interpolation.

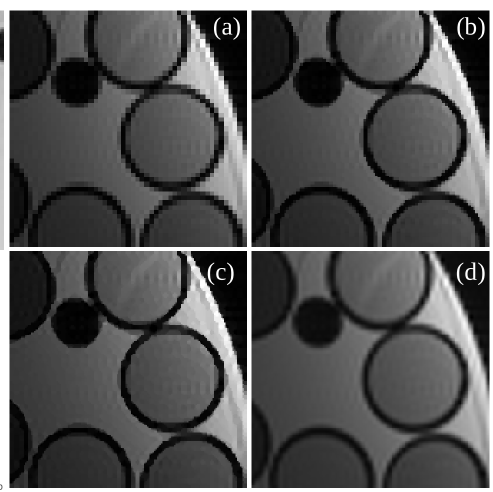

Figure 3: Human brain image at high (a) and low resolution (b). The low resolution image has been corrected with the proposed method (c) and with bicubic interpolation (d). Edges between structures are sharper with our method.