Enhanced MRI Resolution for Clinical Applications

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Magnetic resonance (MR) scanners are used in hospitals to image human body tissues for diagnosis purposes. A compromise between the acquisition time and resolution of the MRI images must always be made. Many Fourier based techniques, like parallel imaging and partial k-space acquisitions are commonly used. Another solution is offered by image processing methods for resolution enhancement. In this paper we discuss a popular video imaging enhancement technique, based on structure controlled Wiener Filters (SCWF), which we have applied to MRI images. We compare it with some known resolution enhancement techniques in the area of image processing.

SCWF is a training based method to up-scale low resolution images, which results in sharp edges and lower noise level [1, 2]. We investigate whether it is possible to approach the diagnostic quality of images that have been acquired at high-resolution from images acquired at a 2 times lower resolution. The method consists of a classification of the spatial structures in a set of images (training set) and of providing a set of enhancement filter coefficients corresponding to each class.

The training uses MR images with both low and high scan resolution. The filters that we find through SCWF training minimize the mean-square error between the high-resolution image and the low-resolution image. We use low resolution images that result from down-scaling of the scanned high-resolution images. The data was acquired on a Philips Achieva 1.5T system. The training set contains 89 brain scans of 17 different patients and every scan consists of 24 slices with a thickness of 2 to 10 millimeters. The average in-plane scan resolution of the high-resolution images is 0.5 to 1.0 mm. We tested the performance of our algorithm with filter apertures of 3-by-3 and 4-by-4 pixels. Larger apertures require too much data for the training.

The performance of the SCWF is benchmarked with some up-scaling algorithms that are currently employed for image processing based MRI resolution enhancement. Bilinear up-scaling is very simple and easy to implement at a low processing power, but it results in images that are generally considered very blurry. Bicubic up-scaling undoubtedly derives a large portion of its popularity from its configurability: two parameters allow the user to make a good compromise between the quality and the algorithm complexity. Bilinear and bicubic are *spatial* up-scaling algorithms, since they operate on the image directly and they are also common in the video-processing domain. In MR Fourier zero-padding is often used. The drawback of the Fourier zero-padding is that it tends to suffer from ringing near the edges. Table 1 depicts the MSE between the enhanced images and the acquired high-resolution images, averaged over the mid-slices of the scans. The parameters of the bicubic filter are tuned to favor the sharpness.

Table 1 *MSE of SCWF compared to bilinear, bicubic and Fourier zero-padding up-scaling.*

Method	Bilinear	Bicubic	Zero-padding	SCWF	SCWF
Aperture	2-by-2	4-by-4	Infinite/All	3-by-3	4-by-4
MSE	916	653	516	463	436
Relative MSE	100%	71%	56%	51%	48%

The table shows that SCWF performs best. The 3-by-3 kernel of SCWF sometimes exaggerates structures, which could explain why the MSE is higher than that of the 4-by-4 kernel. The result from resolution enhancement using a kernel of 3-by-3 voxels is generally sharper than the result of a 4-by-4 aperture. A visual inspection of a specific region of the brain tissue in Figure 1 leads to the conclusion that SCWF (extreme right) resembles the most the acquired high-resolution image, as compared to the previously used methods.

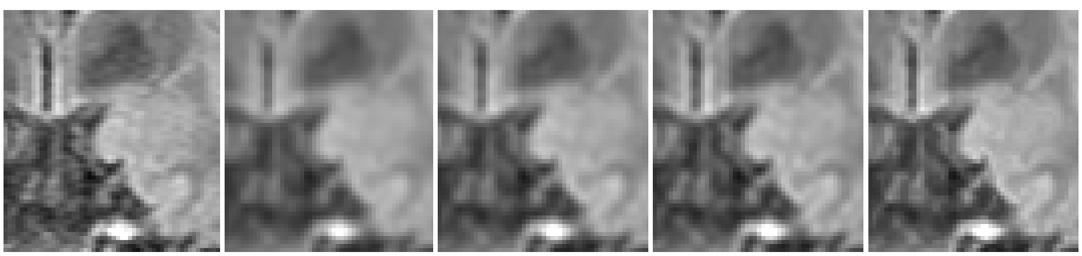

Figure 1 High-resolution brain tissue (original) and up-scaled approximation using bilinear, bicubic, Fourier zero-padding and SCWF with 3-by-3 aperture (from left to right).

As expected, the bilinear result is blurry. This is also true for the bicubic result, even though we chose the parameters of the bicubic algorithm to prevent blurring. The zero-padding algorithm is only marginally sharper than the bicubic. The example and our tests have shown that SCWF obtains some extra sharpening compared to zero-padding, while avoiding ringing or amplification of noise. We conclude that, at the same computational costs as the previously available algorithms, SCWF resolution enhancement provides the best results in terms of MSE, as well as subjective evaluation. Nevertheless, besides the MSE and subjective tests, for a stronger diagnose value of this method, further clinical evaluation must be performed.
Results from this algorithm can be probably be combined with any Fourier based enhancement technique.

References:

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