DIR imaging using Compressed Sensing for Cortical thickness estimation

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Introduction

Double inversion recovery (DIR) is typically used for black blood MRA, cardiovascular imaging, and for the studies related to gray matter diseases. Recently, DIR has shown the potential for volumetric study through gray matter imaging [1]. By suppressing cerebrospinal fluid (CSF) and white matter and by using a fast spin echo based acquisition, cortical thickness measurements near air-bone interfaces could be obtained with significantly reduced susceptibility artifacts compared with the standard MP-RAGE sequence. One drawback however with the DIR acquisition is the long scan time needed to acquire the full 3D data set.

In this abstract, work on combining DIR imaging with the compressed sensing algorithm [2] is presented. Compressed sensing (CS) algorithm can effectively reduce the scan time by random sampling k-space and by using a reconstruction based on a sparsifying transform. Since the DIR image itself obtains only from the cortex regions, the image represents sparsity in image domain. In addition, the cortex has curvy features. Here, we take advantage of these properties in applying the CS algorithm. We show an adequate sparsifying transform, namely the contourlet transform, which is well suited to compactly represent the curvy feature. Comparisons with conventional wavelets under various undersampling ratios are performed and the possibility of estimating cortical thickness by applying this algorithm to volumetry study is presented.

Theory and Methods

DIR image has two properties that make it applicable to CS. First, the image is sparser than general images such as MPRAGE since CSF and white matter are suppressed. Second, the image has many smooth contours since only the cortex remains. Due to these properties, we can apply CS and use an alternate sparsifying transform that can be more effective in representing the smooth contours than the wavelet transform. The contourlet transform [3] has been previously shown to efficiently represent such smooth contours compared to wavelets.

To show the advantage of using the contourlet for DIR images, comparisons were performed by reconstructing images using only 1% of the most significant coefficients for the wavelet transform and contourlet transform. The Peak signal to noise ratio (PSNR) criteria was used. Also, random undersampled k-space data optimized for DIR imaging was acquired and reconstructed by applying the CS algorithm to each transforms. In addition, to show the effects of how volumetric studies would be affected when CS is applied, cortical thickness was estimated and compared using the contourlet transform and CS algorithm under various random k-space undersampling ratios (40, 20, 15, and 10%).

In vivo DIR data were collected using 3T Siemens MRI scanners (TR = 10000ms, TE = 309ms, TI1 = 3340ms, TI2 = 850ms, 256 x 256, slice thickness = 1.3mm, 1.1 x 1.1 x 1.3 mm^3 resolution for 100% sampling, acquisition time = 12min 22sec for 100% 3D coverage). Simulations and data reconstruction were performed using MATLAB R2007b.

Results and Discussion

In Fig. 1, images reconstructed using only 1% of the most significant coefficients are shown. Images using contourlet transform (PSNR: 8.32) resulted in a higher PSNR than the wavelet transform (PSNR: 7.89) and also shows better resolved images. In Fig. 2, using undersampled random k-space data (20% k-space sampling), reconstructed images using the contourlet transform (PSNR: 3.67) resulted in higher than wavelet transform (PSNR: 3.59) and better representation of the curvy features. From these two experiments, it can be seen that DIR images can be effectively represented by a sparsifying transform and that the contourlet can be more efficient compared to the wavelets due to its curvy feature.

Fig. 3 shows difference images between the fully sampled reference image and the reconstructed image for various undersampled k-space data (undersampling ratio: (a) 40%, (b) 20%, (c) 15%, (d) 10%) reconstructed with the CS applied contourlet transform. Also shown are the line plots illustrating cortical thickness measurement variations for the given undersampling ratio (top: 100% sampling, bottom: undersampling). It can be seen that cortical thickness measurement errors are within noise factors for up to approximately 15-20% undersampling.

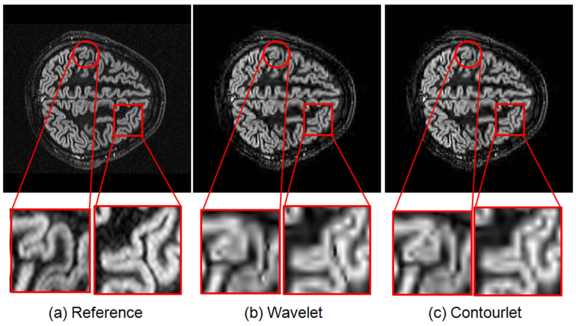

Figure 1.

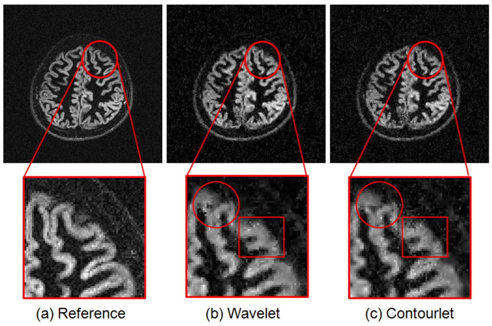

Figure 2.

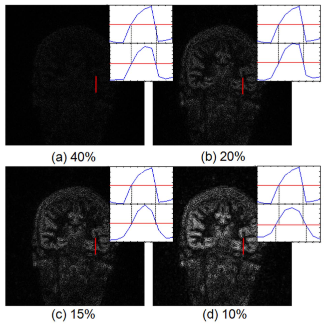

Figure 3.

Figure 1: Images reconstructed using 1% most significant coefficients (PSNR (b) 7.89, (c) 8.32)

Figure 2: Reconstructed images using 20% sampled k-space data (PSNR (b) 3.59, (c) 3.67)

Figure 3: Difference images between fully sampled image and undersampled k-space data image. Line intensity plot for the region given.

Conclusion

One of the drawbacks of 3D DIR imaging is its long scan time. To solve this problem, we applied CS algorithm to undersampled k-space DIR data. Generally, wavelet transform is used as a sparsifying transform in CS reconstruction. But DIR images has many smooth contours, using a directional filter bank such as the contourlet as the sparsifying transform, it can be more effective than using wavelet transform and more undersampling can be achieved. And as we have seen, although cortical thickness is blurred when the undersampling ratio is increased, sufficiently accurate estimation is possible to up to approximately 15% sampling.

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References

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