An Approach to Improve the Effectiveness of Wavelet and Contourlet Compressed Sensing Reconstruction

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Target audience: Those interested in exploring the effectiveness of new compressive sensing (*CS*) approaches to improve the spatial resolution of textures present in MR reconstruction of truncated *k*-space data sets to allow the discrimination of neurological diseases.

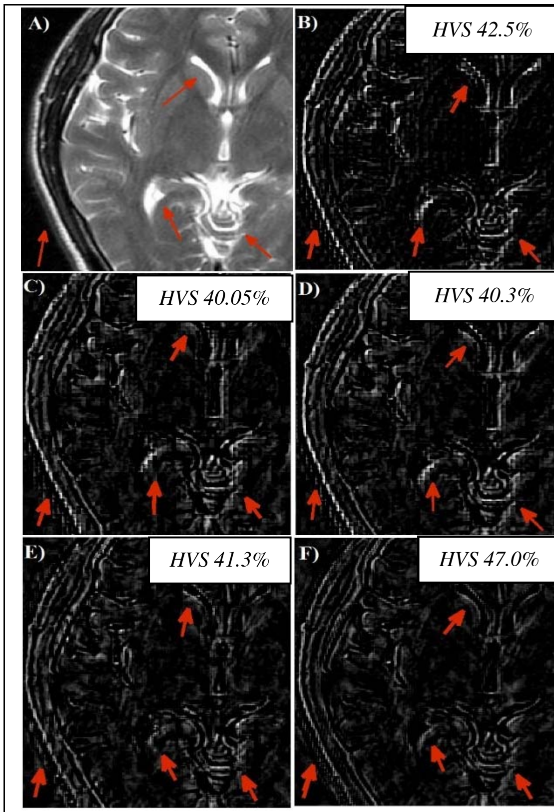
Purpose: Reconstruction of MR images with high spatial resolution is a prerequisite for the application of texture analysis of MR brain images for discrimination of neurological diseases. CS reconstruction techniques achieve faster throughput (higher temporal resolution) by under-sampling truncated *k*-space data while retaining high spatial resolution through the application of sparseness properties [1]. The explanations for distortions introduced during discrete Fourier transform (*DFT*) reconstruction of truncated *k*-space data sets are well established: e.g. truncation artifacts are introduced by discontinuities across the ends of the *k*-space data set which mathematically must be considered as a cyclic data set during *DFT* reconstruction [2]. Recently it has been suggested that these same *k*-space continuity constraints must also impact the achievable resolution during *CS* reconstructions which repeatedly uses the *DFT* and *IDFT* to move data between *k*-space, image and other domains [3]. A high resolution *k*-space extrapolation enabled (*Hi-KEE) CS* variant was proposed to overcome the *k*-space discontinuity issue [3]. In this paper we qualitatively compare the image texture characteristics of a MR brain data set following *DFT*, *CS-Wavelet* [1] and *CS-Contourlet* [4] reconstructions with new *Hi-KEE* variants of these approaches, *Hi-KEE-CS-Wavelet* and *Hi-KEE-CS-Contourlet*.

Methods: An under-sampled *CS* data set was prepared by truncating a high-resolution *512 x 512 k*-space data set [5] to *128 x 128* followed by a random variable density 33% sampling pattern including a fully sampled 10% core of size 0.1 as per [1]. The software setting for *CS-Wavelet* [1] and *CS-Contourlet* [4] were left unchanged. As suggested in [3], the *Hi-KEE* data sets were prepared by zero padding both the *CS* data set and the *CS* sampling pattern to *256 x 256* before applying the *CS-Wavelet* and *CS-Contourlet* algorithms. The High Dynamic Range Visual Difference predictor (*HDR-VDP-2.0*) [6], a measurement criteria based on the human visual system (*HVS*) was used to compare *CS* and *Hi-KEE* images with the reference (original 512x512 data set) to determine whether a human observer would likely notice a difference between the reconstructions. *The HDR-VDP-2.0* toolbox provides a visual representation, a difference probability map, and a *HVS*-relevant metric, a numerical value indicating the quality of image.

Results: The arrows indicate regions of interest in the images. Image (A) shows the original high resolution 512x512 brain dataset. The higher *VDP* intensities in the probability maps for (B) 128x128 *IDFT* and C) 128x128 *CS-Wavelet* reconstruction show a higher probability of a difference being detected by a human observer. The probability difference map (D) for 128x128 *CS-Contourlet* shows lower intensity over the same areas marked with red arrows, indicating the better recovery of contours. The same components are even more clearly recovered using (E) 256x256 *Hi-KEE-CS-Wavelet* of the 128x128 truncated data set. The least intensive image of (F) 256x256 difference probability map for *HiKEE-CS-Contourlet* represents the smallest probability of difference detection by a human observer

Discussion: The lower intensity in the quantitative probability difference maps indicate the CS-Contourlet outperforms the CS-Wavelet sparse transforms by providing a sparser representation of smooth contours with much less complexity and optimal approximation rate. The *VDP-HVS* relevant quality metric indicated the superiority of *Hi-KEE-CS-Contourlet* with resolution enhancement compared to the *CS-Wavelet*, *Hi-KEE-CS-Wavelet* and *IDFT* reconstructions

Conclusion: An investigation of the theoretical impact that CS reconstruction has on the characteristics of *k*-space data has led to insight into the limitation of the *CS-Wavelet* reconstruction approach and led to a more reliable reconstruction algorithm which makes use of *k-space* extrapolation properties inherent in CS reconstruction.



A) Original 512x512 *IDFT* reconstruction. *HDR-VDP* visualization maps of the probability of a human observer being able to distinguish between B)128x128 *IDFT* reconstruction, C) 128x128 *CS-Wavelet,* D) 128x128 *CS-Contourlet,* E) 256x256 *Hi-KEE-CS-Wavelet* and F) 256x256 *Hi-KEE-CS-Contourlet*

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