EVALUATION OF COMPRESSED SENSING MR RECONSTRUCTION QUALITY USING SIGNED JUST NOTICEABLE DIFFERENCE (JND) ANALYSIS

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Introduction:

Compressed sensing MR imaging (MRI) exploits the natural compressibility of the acquired data without significant quality degradation. This offers great potential to new clinical applications that require fast dynamic imaging. Unfortunately, the computational burden associated with the optimization involved in compressed sensing limits its clinical practicality. Many alternatives and trade-offs are explored in compressed sensing MR reconstructions for improved efficiency and making compressed sensing MRI a clinically viable option. A challenge associated with this significant effort is how to successfully assess the performance of each reconstruction algorithm with human visual perception in mind. This is a natural idea given that the ultimate judge of any image is the remarkably complex human eye and visual cortex. Often used MR image quality measures are MAE, MSE, SNR and PSNR. In spite of being simple, well defined, and widely accepted with clear physical meanings, these metrics fail to predict human perceived image quality, because (1) not every change in an image is noticeable; (2) not every region on an image receives the same attention; (3) not every change leads to a same desired or undesired outcome; (4) not every change with a same magnitude yields a same perceptual effect.

We propose to incorporate human perception model into assessing the quality of compressed sensing MR reconstruction algorithms. More specifically, we seek to measure the perceptual changes or degradation in reconstructed MR images using the *signed* just noticeable difference (JND) analysis, providing an overall "quality" map or score for each MR image under consideration. The just noticeable difference (JND) is the minimum amount of change that needs to be for a person to recognize there is some type of change in a specific stimulus. JND metrics of an image can be computed using a visual discrimination model (VDM), for example, the one developed at Siemens Corporate Research. State-of-the-art JND analysis [1] considers only the absolute value of the difference to predict the magnitude of change visibility. However, the effects of compressed sensing MR reconstruction methods are much more complex, and can alter the image appearance in ways that simultaneously increase the visibility of some features (e.g., artifacts) while decreasing the conspicuity of others (e.g., structural boundaries). Properly evaluating changes in image appearance in those cases requires knowledge about the direction as well as the magnitude of difference visibility. In addition, the direction of change offers important insight for improving the reconstruction methods.

Method:

Let us assume jnd_{test} and jnd_{ref} be JND maps of a test and the corresponding reference image for a specific channel and orientation. We define the perceived difference visibility between the two images for a specific frequency and orientation channel as $jnd_{diff} = jnd_{test} - jnd_{ref}$ (1).

With this definition, jnd_{diff} in (1) could be with negative values. In our approach, Eq. 1 is first applied independently to each frequency and orientation channel. When the difference visibility occurs primarily in one or a few channels, analysis of those individual channels can be sufficient. Quite often, however, image differences are more complex, involving significant changes occurring across sets of frequency and/or orientation channels. For those cases, to determine the maximum response $jnd_{max}(x)$ at pixel location x across multiple frequency and orientation channels, we introduce the following definition

$$jnd_{max}(x) = \begin{cases} max \mid jnd_{diff}(x)\mid, jnd_{diff}(x) > 0 \\ -max \mid jnd_{diff}(x)\mid, jnd_{diff}(x) < 0 \end{cases} \quad (2)$$

Where $max\mid f(x)\mid$ is the maximum absolute value of $f(x)$. The maximum response $jnd_{max}(x)$ defined in (2) captures the information about both the amount of change and the direction of change, i.e., the value of $jnd_{max}(x)$ is positive when not only the magnitude of $jnd_{diff}(x)$ is the maximum, but also the corresponding JND value in a test image is larger than the one in the reference image at location x; the value of $jnd_{max}(x)$ is negative when the corresponding JND value in the test image is smaller than the one in the reference image at x. Summary JND metrics can be evaluated by spatial pooling across pixel locations, typically by computing the mean, a histogram percentile or Minkowski summation. These Metrics can be computed across an entire image or within regions or frequency/orientation channels containing specific features of interest.

Results:

The implementation of our proposed system has been applied to cardiac MR images reconstructed using two different methods. The reference image in this study is an original image reconstructed using the full MR data samples, as shown in Figure 1(b). Two test images, shown in Figure 1(a) and 1(c), are reconstructions of the same image using TVCMRI (Total Variation L1 Compressed MR Imaging) and RecPF (Reconstruction from Partial Fourier data) compressed sensing methods, respectively. The purpose of this study is to demonstrate its potential value of JND map in assessing image quality and comparing the overall performance of reconstruction methods. When two identical images are compared, the output JND map should be of white color, indicating zero change of visibility everywhere. By using signed JND maps, it is possible to distinguish artifacts from loss of anatomical details. As indicated in both JND maps in Figure 1(d) and 1(e), blue color is more visible in small vessel areas, and red color is more pronounced in relatively large smooth areas. This important observation implies that the loss of anatomical structures (blue color) happens

(a) TVCMRI   (b) Original   (c) RecPF
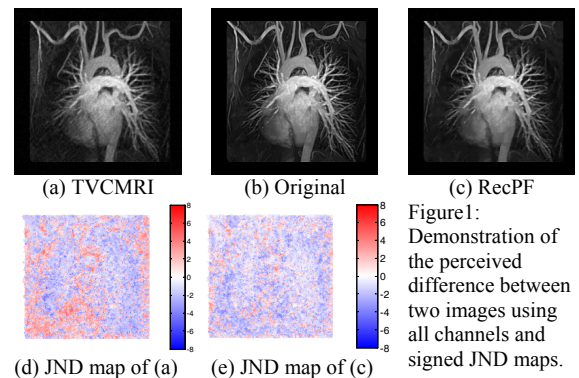
(d) JND map of (a)   (e) JND map of (c)

Figure1: Demonstration of the perceived difference between two images using all channels and signed JND maps.

primarily in small vessel areas, and artifacts (red color) are often introduced in relatively smooth areas, as clearly illustrated in Figure 1(d). It is worth noting that the JND map in Figure 1(e) appears to be lighter overall in both red and blue color in comparison with the JND map in Figure 1(d); this leads to the conclusion that the RecPF reconstruction approach may perform better than the TVCMRI approach.

[1] J. Lubin. "A visual discrimination model …." Visual Models for Target Detection and Recognition, 1995, pp. 245-283.