Metrics for quantifying the quality of MR images

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1. Introduction: New MRI acquisition and reconstruction methods are created at a rapid pace, imposing a clear need for quantifying the quality of the reconstructed images against standard high quality image references. This is a difficult task because it involves both, objective measures and subjective appreciation. The Root Mean Squared Error (RMSE) has been commonly employed for this task in spite of its inability to capture truly relevant differences and its tendency to accentuate perceptually irrelevant nuances [1] [2]. This inability can be seen in figure 1, where two very different quality images show the same RMSE. In this work we propose two indexes, which consider perceptual measures: Null space analysis and Just Noticeable Differences (JND) scanning. Experiments show that they are closer to the subjective opinion than the RMSE value.

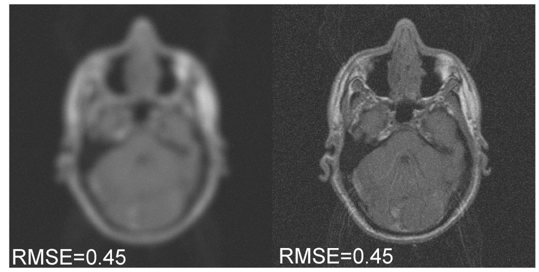

Fig. 1. Images with same RMSE (with respect to the original) but perceptually different

2. Methods: The purpose of the proposed indexes is to generate one number telling "how close" is one image to another.

2.1 Null space analysis: The idea is to measure the perceptually relevant information lost when transforming a reference image A, into another image D. It is achieved finding a linear transformation from A to D that maximizes its null space dimension. Let T be a transform matrix such that D=TA. Since there are N(N-1) degrees of freedom (N is the number of pixels), T is selected such that its null space has the maximum allowable dimensions (N-1). In this way, T can be computed as $T = De^* / \langle e, A \rangle$, where *e* is a reference image that determines a space that is orthogonal to the null space of T. We will simply use $e = (A+D)/2$. Then, we set $A = A^K + A^I$, where A^K and A^I are the lost and preserved information of the image after the transformation T respectively. Afterward, A^K is weighted with the Contrast Sensitivity Function (CSF) [3] to match the perceptual significance of the lost information $\phi = W^{-1} \cdot CSF \cdot W \cdot A^K$, with *W* the Fourier Transform. Finally, the index *Null Space Analysis* (NSA) is the energy of Φ.

2.2 JND scanning: JND [4] is the maximum threshold below which distortions are not perceived in a given pixel. The JND profile is a binary image that tells where the differences between the pixels of two images are above that threshold and thus noticeable. As such is not a good measurement of quality because it does not quantify the overall error. We propose to use JND in a slightly different way, measuring how the image differences disappear as we begin to decrease the contrast of both images. The first intensity differences to disappear would show the less distorted pixels and the last ones the most distorted. The JND threshold is a step function as shown in figure 2a for each pixel. If the image contrast images changes, the threshold moves horizontally (figure 2b). All possible thresholds can be integrated as in figure 2c. This last figure is interpreted as how probable is to see a pixel's distortion for all possible contrasts. For example, an intensity difference x1 (figure 2c) will not be seen, independently of the contrast, whereas an intensity difference x2 is visible in approximately half of the contrast levels. Finally, each pixel is assigned to a probability of visibility taken from the curve for a given distortion. To summarize this information we chose to compute the quotient of the number of pixels with probability one to the ones with probability zero, obtaining the index *JND Scanning* (JNDS). Empirically we found that these curves have in general a steep transition, therefore pixels with middle values are less frequent than the extreme cases (zero and one).

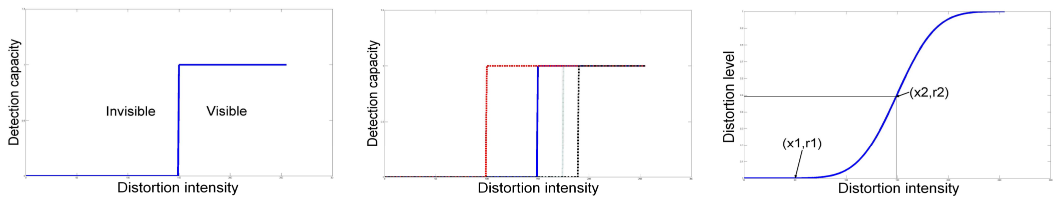

Fig. 2. a) JND threshold is a step function, b) JND threshold will move if the contrast of the image change, c) integration of all possible thresholds.

3. Results: We compared the results obtained using both indexes against those obtained using RMSE for a set of 150 brain MR images. Although there is some correlation between the results from the indexes and those from the RMSE, their dispersion suggests that the proposed measures are more sensitive to the image distortions.

In order to test their correlation with human perception, we asked volunteers to grade, from 1 (worst) to 5 (best), 15 MR images (figure 1 shows two examples) with different distortions (noise, blurring, Gibbs ringing, field inhomogeneities) but with similar RMSE values (between 0.448 and 0.452). The results are shown in figure 3. In figure 3a, as expected all images present roughly the same RMSE, nevertheless they are perceptually very different. That is not the case with the proposed indexes that show a better agreement with the subjective qualification.

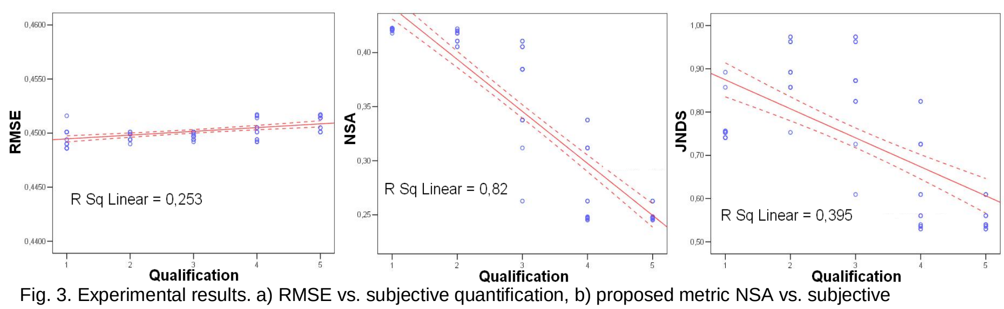

Fig. 3. Experimental results. a) RMSE vs. subjective quantification, b) proposed metric NSA vs. subjective quantification, and c) proposed metric JNDS vs. subjective qualification.

4. Discussion: The proposed indexes have a better performance than the RMSE measure for moderately distorted images (of the kind obtained with reconstruction methods). Perceptually different images, with very close RMSE, are judged in close agreement to human observers by both indexes. The second index is innovative since it uses an intuitive concept to evaluate image quality, and the results display its merits. It is important to keenly investigate other forms of image degradation, asides from contrast reduction, to include them in the index calculations. We are convinced that considering the image quality perception as a linear transformation can be a new and efficient way to approach this difficult problem.

References: [1] Ivkovic, et al, (ICASSP '04) 3, p. 713, 2004. [2] Girod, MIT Press, p. 207-220, 1993. [3] Peli, J. Optical Society of America A, 18, 283-293, 2001. [4] Chou, et al. IEEE T. Circuits and Syst. 5, 467, 1995.