# *Informed* RESTORE for Removal of Physiological Noise Artifacts in Low Redundancy DTI Data

**L-C. Chang[1], L. Walker[2], B. Behseta[3], and C. Pierpaoli[2]**

[1]Department of Electrical Engineering and Computer Science, The Catholic University of America, Washington, DC, United States, [2]STBB, NICHD, National Institutes of Health, Bethesda, Maryland, United States, [3]Pediatric & Developmental Neuroscience Branch, NIMH, National Institutes of Health, Bethesda, Maryland, United States

**Introduction:** Robust tensor fitting approaches, such as Geman-McClure M-estimator [1] and the Robust Estimation of Tensors by Outlier Rejection (RESTORE) [2] are effective methods for improving tensor estimation on a voxel-by-voxel basis in the presence of artifactual data points in the diffusion weighted images (DWIs). However, all robust tensor fitting methods rely on data redundancy [3]. The estimated parameters may not be reliable if the data set does not have enough good data points (at least 50% in each non-collinear, unique sampling direction) to correctly identify outliers. This data redundancy requirement makes using RESTORE with clinical DTI datasets with less than 30 - 40 DWI volumes problematic. In this paper, we introduce a modification of the original RESTORE method, called *informed* RESTORE (*i*RESTORE) to effectively remove artifacts caused by cardiac pulsation and subject motion from a low redundancy DTI data set.

**Methods:** *i*RESTORE is based on the notion that physiological noise artifacts are more likely to result in signal drops rather than signal increases [4]. This new algorithm uses an iterative nonlinear least-squares method with constant weights. Outlier detection and exclusion is done in a step-by-step approach in voxels where $\chi^2$ is above a normal level. After each iteration, the data point with the maximum negative residual (i.e., the lowest signal) is identified and excluded as an outlier from the next iteration. At each iteration the condition number [5, 6] is computed to ensure that the design matrix is not ill-conditioned. Also, the direction vectors are projected onto a predefined gradient sampling scheme to verify that the remaining data is not severely directionally unbalanced [7]. The iteration continues until it reaches a user defined maximum number of excluded points or an acceptable value of the reduced $\chi^2$. The algorithm combines a greedy and a backtracking approach, i.e., making the locally optimal choice at each stage with the hope of finding the global optimum, and back tracking the previous iteration to ensure a solution is found [8].

This method is demonstrated on data from a 7 y/o female healthy control. DWIs were acquired on a 1.5T GE scanner, using an eight channel coil. The acquisition consisted of 4 repeats of the basic 6 directions at b=1000 s/mm$^2$ and 1 b=0 image, plus 2 repeats of the basic 6 directions at b=500 s/mm$^2$ and 1 b=0 image, for a total of 42 volumes. No cardiac gating was performed. Prior to tensor computation DWIs were corrected for motion and eddy current distortions [9] and EPI distortion [10]. Tensor fitting was performed three times on this representative dataset, once using the nonlinear least-square (NLS), once using the original RESTORE, and once using the *i*RESTORE method.

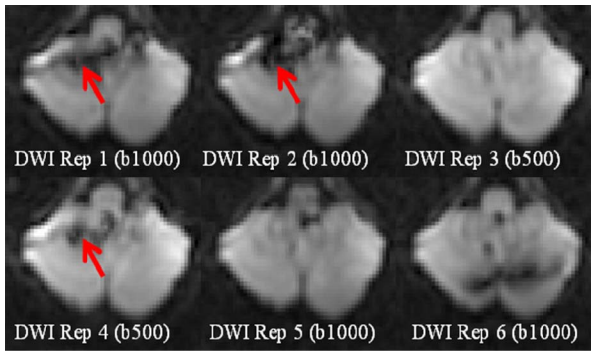


Figure 1. An ungated low redundancy DTI data set (the basic 6 directions with 6 repeats) where the physiological artifacts occurred in 50% of DWIs in one of the sampling directions.

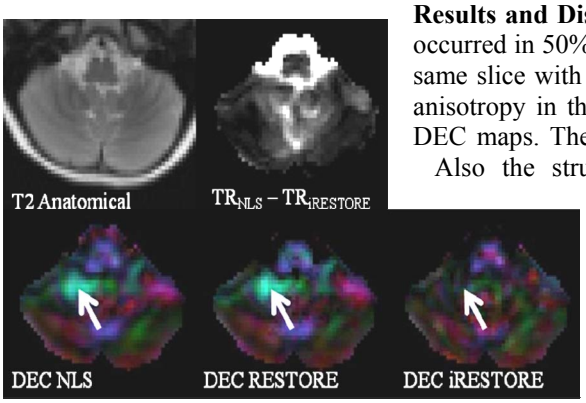


Figure 2. The DEC map obtained from NLS, original and informed RESTORE methods, and the subtraction of the Trace map between NLS and informed RESTORE.

**Results and Discussion:** Figure 1 shows a slice with a region in which physiological artifacts occurred in 50% of DWIs (indicated by red arrows). Figure 2 shows DEC maps obtained in the same slice with the three different tensor fitting approaches. Pulsation artifacts cause spurious anisotropy in the cerebellum [4, 11] indicated by a white arrow on the NLS and RESTORE DEC maps. The proposed *i*RESTORE method, however, does not show spurious anisotropy. Also the structure of the brain stem is more clearly defined when processed using *i*RESTORE. A subtraction of the mean Trace maps (TR$_{NLS}$ minus TR$_{iRESTORE}$) shows a local reduction of TR by processing using *i*RESTORE in the medial cerebellar region where cardiac pulsation outliers have been previously demonstrated [4].

**Conclusions:** Erroneous tensor derived quantities using RESTORE may occur in low redundancy clinical human brain DTI data. This work proposes a method using the characteristics of physiological artifacts to effectively remove them from low redundancy data. The *i*RESTORE algorithm improves the robustness of outlier rejection in the presence of signal dropout artifacts, and makes it more practical for clinical DTI data analysis.

**References:** [1] Mangin J, et al. *Med Img Analy*, 6:191-198, 2002. [2] Chang L, et al. *Magn Reson Med* 2005, 53:1088-1095. [3] Bevington P, McGraw-Hill Book Company, New York, NY, 1969. [4] Pierpaoli C, et al. *ISMRM* 13th Ann. Meeting, Toronto, 2003, p. 1170. [5] Skare S, et al. *J of Magn Reson* 2000, 147: 340 -352. [6] Chang L, et al. *ISMRM* 17th Ann. Meeting, Honolulu, 2009, p. 5707. [7] Chang L, et al. *SPIE Proc.* 2010, Vol. 7623, 762328. [8] Cormen T, et al. McGraw-Hill Book Company, New York, NY, 2009. [9] Rohde GK, et al. *Magn Reson Med* 2004; 51: 103-114. [10] Wu M, et al. MICCAI, 11(2), 321-329. [11] Walker L, et al. *NeuroImage* 2010 (in press).