A clinical evaluation of a novel, retrospective and entropy-based intensity inhomogeneity correction method in 3T MRI

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Target audience: Radiologists, Clinicians and MR Researchers **Purpose:** Intensity inhomogeneities remain an issue in high-field MRI and can degrade clinical interpretability of images. To improve image quality in a fast, robust and a fully automated fashion, we developed and clinically validated a novel image inhomogeneity correction method. Two implementations, i.e. a 2D and a 3D, were evaluated in a blind study.

Methods: *Correction Method:* We propose a correction method which builds upon work of [1], [2]. More specifically, and in contrast to the already existing methods, we employ a bounded Nelder-Mead simplex optimizer to minimize the Shannon entropy of the normalized joint intensity-gradient histogram. We model the bias field as a low-resolution image (5x5 for 2D and 3x3x3 "kernel matrix" for 3D implementation) and interpolate to the high resolution using cubic b-splines. The coefficients of the kernel matrix are direct inputs into the optimizer. Besides the optimization process, the proposed method implies subsampling (ca. to 100x100 pixel), background removal (with Otsu thresholding [3]) and histogram initialization (robust bin size estimates using Freedman&Diaconis and IQR [4]).

Evaluated Data: 21 MRI clinical neurological datasets were assessed. To increase the validity of the assessment, a wide range of different contrasts/sequences was used (FLAIR, MPRAGE, FLASH, TSE, SWI and DWI). The dataset is divided into healthy controls (N=11) and cases with pathologies (N=10). Each image was acquired without any bias field correction and processed 1) using the built-in Siemens solution, *Pre-Scan Normalize* (PSN), 2) using PSN with the 2D-, 3) using PSN with the 3D-implementation of the proposed method, as well as 4) using only the 2D- and 5) using only the 3D-implementation. *PSN* uses additional body coil images to remove the bias field. The ten cases with pathological findings included metastasis, white-matter changes and post-stroke lesions. The datasets contains images in transversal as well as in coronal plane. Results for 1), 2) and 3) are shown in Fig. 1.

Clinical Assessment: Two trained radiologists evaluated each image in a blind fashion and both agreed on each rating. Five ratings (5=excellent, 4=very good, 3=good, 2=adequate, 1=poor) were used for five criteria: 1) *Symmetry* - of corresponding image intensities between the two brain hemispheres; 2) *Intra-Slice homogeneity* - the intensity homogeneity in corresponding tissue classes within a slice; 3) *Inter-Slice homogeneity* - the intensity changes across image slices (e.g. z-direction); 4) *Clinical information conten*t, and 5) *Overall image quality* impression.

Results: One-side paired t-tests show statisticaly significant improvements ($p<0.05$) in all evaluated criteria, except for the *inter-slice homogeneity*, when the proposed 3D method + PSN is compared to PSN only (c.f. Figure 1). The 2D multi-slice implementation + PSN shows improvements ($p<0.05$) only in *Intra-Slice homogeneity* compared to PSN only. The mean processing times are 54.8 sec (σ=25.35) for the 2D multi-threaded implementation and 43.1 sec (σ=26.91sec) for the 3D implementation (WindowsXP 32-bit, i5 4-core, 3.2GHz, 4GBRAM).

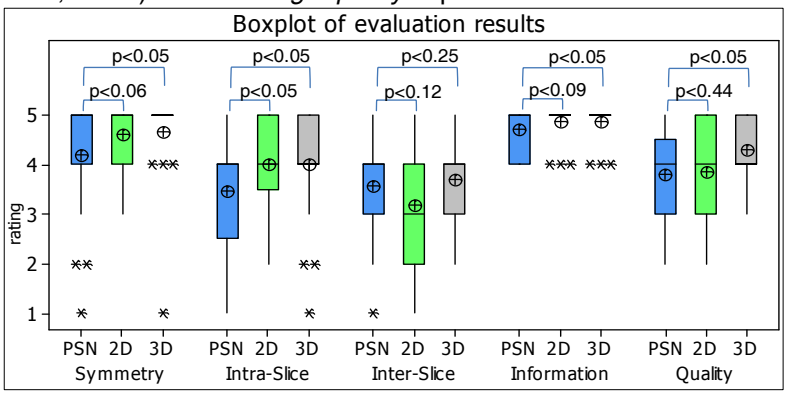

Figure 1: Evaluation results for the whole dataset (N=21) Comparison of current Siemens built-in solution (PreScan-Normalize, PSN) and 2D/3D-implementations of proposed method in addition to PSN (⁎: Outlier, ⊕ : Mean value)

Discussion: Our analysis shows that the combination of the proposed 3D image-based method and PSN works best. The 3D method improves the results of PSN in reasonable time over almost all of the assessed criteria and in all images (controls and pathologies alike). The 2D implementation improves (over PSN) the symmetry, homogeneity, image quality and clinical information content only in healthy controls, but degenerates inter-slice homogeneity, symmetry and image quality impression in images with pathological findings. The sole application of either the 2D or the 3D implementation cannot clinically substitute PSN. We prefer an entropy-based approach over existing methods (e.g. N4 [5]) to eliminate any user interaction or adjustments.

Conclusion: We have shown that the combination of the 3D implementation of the proposed method and the current built-in Siemens solution is able to improve the clinical impression of 3T neuroradiological MRI. This method is fully automated, fast, robust (tested on diverse MR sequences) and unaffected by the presence of tested pathologies.

References: **[1]** B. Likar et. al, *IEEE Trans Med Imag,* (2001)pp.1398-1410 **[2]** J. V. Manjón et. al, *Med Image Anal,* (2007); 336-345 **[3]** N. Otsu, *IEEE Trans Syst Man Cybern* (1979),pp. 62-66 **[4]** D. Freedman, P. Diaconis, *Probab Theor Relat Field*,(1981)pp.453-476 **[5]** N.J.Tustison, *IEEE Trans Med Imag* (2010),pp.1310-1320