Intensity Inhomogeneity Correction in MRI via Low-Frequency DCT Coefficients Optimization

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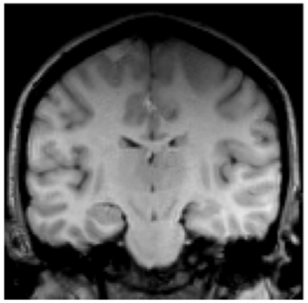
Introduction

- Intensity inhomogeneity in magnetic resonance (MR) images
  - Smoothly varying bias field over a whole image
  - Causes
    - Static magnetic field inhomogeneity
    - Imperfection in the coils
    - Inhomogeneous RF penetration in body tissues



Intensity inhomogeneity in MR brain image[1]

  - Accuracy of MR image analysis can be considerably degraded.
    - Segmentation, registration, quantification, etc.

[1]U. Vovk, F. Pernus, and B. Likar, “A review of methods for correction of intensity inhomogeneity in MRI,” *IEEE Trans. Med. Imaging*, vol. 26, no. 3, pp. 405-421, 2007

Related works

- Existing retrospective methods[1]
  - Filtering
    - Low-frequency inhomogeneity is separated from the high-frequency anatomical structures via low-pass filtering.

    → Anatomical structures may be mistakenly removed by filtering.
  - Surface fitting
    - Fit a parametric surface to a set of image features that contains information on the intensity inhomogeneity.

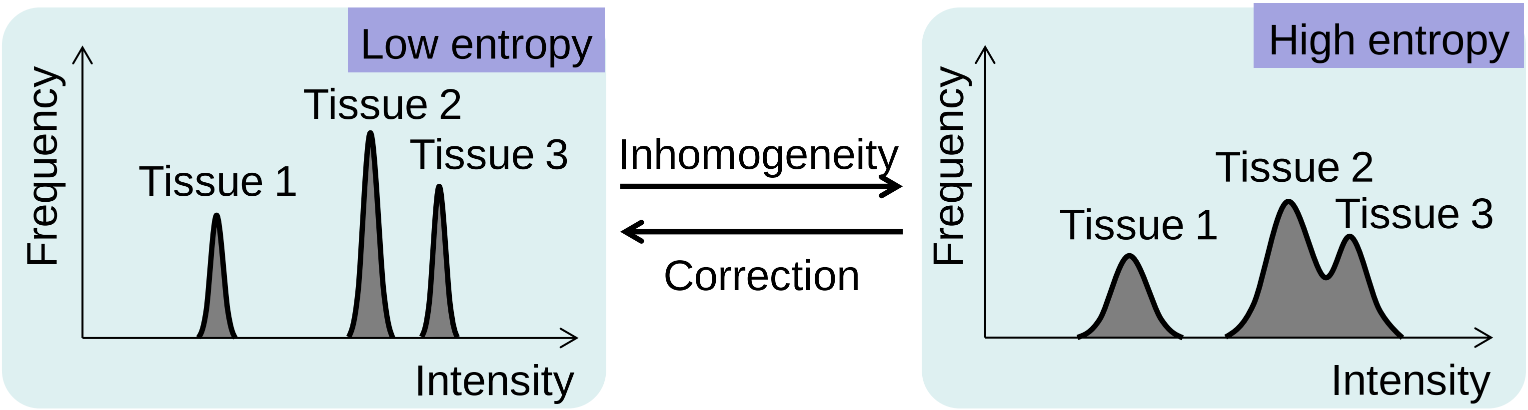
    → Successful if homogeneous areas are large and distinctive.
  - Segmentation-based
    - Merge segmentation and intensity inhomogeneity correction.

    → Require an additional segmentation algorithm.

[1]U. Vovk, F. Pernus, and B. Likar, "A review of methods for correction of intensity inhomogeneity in MRI," *IEEE Trans. Med. Imaging*, vol. 26, no. 3, pp. 405-421, 2007

Related works

- Existing retrospective methods[1]
  - Histogram-based
    - Minimize the image (histogram) entropy.
    - Need no initialization and/or prior knowledge.
    - Image structures are relatively well preserved.
    - Fully automatic and highly general



Effect of the intensity inhomogeneity in image histogram

[1]U. Vovk, F. Pernus, and B. Likar, "A review of methods for correction of intensity inhomogeneity in MRI," *IEEE Trans. Med. Imaging*, vol. 26, no. 3, pp. 405-421, 2007

Related works

– Histogram-based

- Nonparametric Non-uniform Intensity Normalization (N3)[2]
  - Intensity inhomogeneity model: Multiplicative

$$v(x) = u(x) f(x) \xrightarrow[\text{noise free}]{\text{log-transform}} \hat{v}(x) = \hat{u}(x) + \hat{f}(x)$$

↓ PDF (histogram)

$$V(\hat{v}) = F(\hat{f}) * U(\hat{u})$$

$v(x)$: measured image
$u(x)$: true image
$f(x)$: bias field

F can be viewed as **blurring** the intensity distribution ***U***

  - Find ***F*** that maximizes high frequency components of ***U*** via iteration process.
    - » Makes the image intensity histogram as sharp as possible.

[2]J.G. Sled, and A.P. Zijdenbos, "A nonparametric method for automatic correction of intensity nonuniformity in MRI data," *IEEE Trans. Med. Imaging*, vol. 17, no. 1, pp. 87-97, 1998

Related works

– Histogram-based

- Information minimization

  – Intensity inhomogeneity model: Multiplicative and additive[3]

$$v(x) = u(x)m(x) + a(x) \xrightarrow[\text{Inverse estimation}]{} \tilde{u}(x) = v(x)\tilde{m}^{-1}(x) + \tilde{a}^{-1}(x)$$

$v(x)$: measured image
$u(x)$: true image
$m(x)$: multiplicative component
$a(x)$: additive component

where $\tilde{m}^{-1}(x) = \dfrac{1}{m(x)}$ and

$$\tilde{a}^{-1}(x) = -\frac{a(x)}{m(x)}$$

  – Find $\tilde{m}^{-1}(x)$ and $\tilde{a}^{-1}(x)$ that minimize image entropy $I[\tilde{u}(x)]$.

  – $\tilde{m}^{-1}(x)$ and $\tilde{a}^{-1}(x)$ are linear combinations of smoothly varying basis functions (polynomial), respectively.

[3]B. Likar, M.A. Viergever, and F. Pernus, “Retrospective correction of MR intensity inhomogeneity by information minimization,” *IEEE Trans. Med. Imaging*, vol. 20, no. 12, pp. 1398-1410, 2001

Proposed method

- Low frequency DCT coefficients optimization for correcting the intensity inhomogeneity
  - Band-limited bias field
    - The bias field is known to be **smoothly varying**.
    - Expected to have no spatial high-frequency components.
  - Discrete cosine transform
    - Great energy compaction
      - Any meaningful smooth varying field can be described only a few low-frequency coefficients.

MR image of a phantom

Proposed method

- Intensity inhomogeneity model
  - Multiplicative model

$$v(x) = u(x) f(x) \longrightarrow \tilde{u}(x) = \frac{v(x)}{f(x)}$$

$v(x)$: measured image
$u(x)$: true image
$f(x)$: bias field
$\tilde{u}(x)$: estimated image

- Assumption: Bandwidth of the bias field may be limited.

→ Set its frequency coefficients above a certain bandwidth to zero.

$$f(x) \xrightarrow{DCT} F(n) = \begin{cases} \sqrt{N} & n = 0 \\ F(n) & 1 \le n \le th \\ 0 & \text{otherwise} \end{cases}$$

where N is total # of pixels in the image.

→ Find optimal DCT coefficient $F(n)$
to minimize the entropy of estimated image $I[\tilde{u}(x)]$.

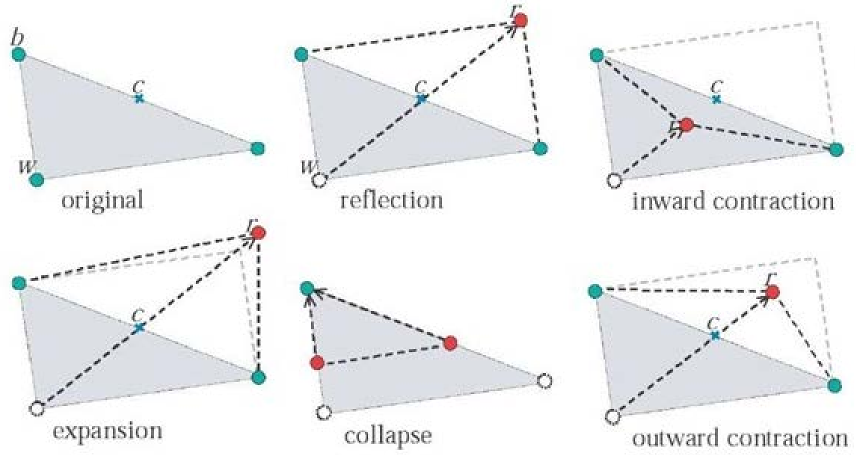
Proposed method

- Objective function

$$E(F(n)) = I[\tilde{u}(x)] + \lambda C = I\left[\frac{v(x)}{f(x)}\right] + \lambda C$$

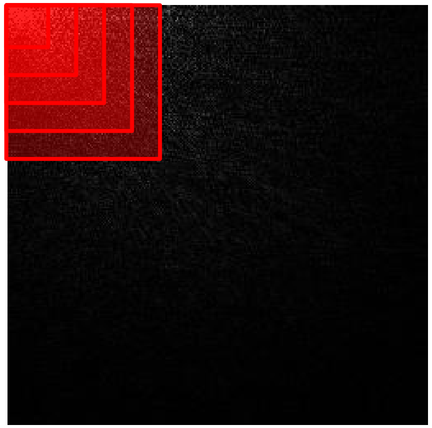
where $I[\cdot]$: entropy
λ : weight parameter of the constraint
C: number of pixels such that $f(x) < \varepsilon$

- Optimization method
  - Downhill simplex
    - It is known as the robust method when the objective function has many local minima.



Proposed method

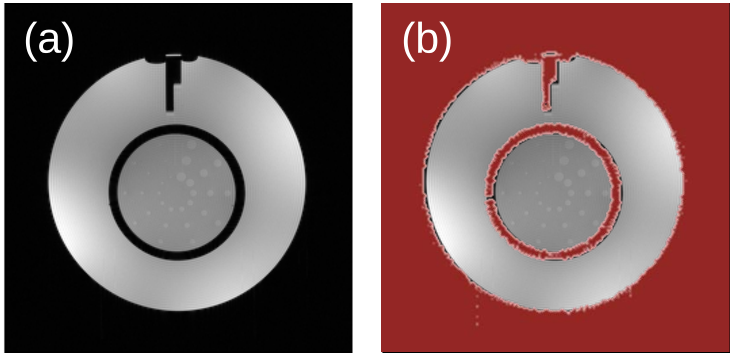
- Multi-stage optimization
  - The objective function is non-convex and can have a lot of local minima.
  - To avoid local minima, gradually increase the bandwidth of the estimated bias field via downhill simplex optimization.



Gradual bandwidth increase in the DCT domain

Proposed method

- ROI mask
  - The background dark area can interfere with inhomogeneity correction.
  - The mask is determined via automatic thresholding based on average intensities around four corners of the image.



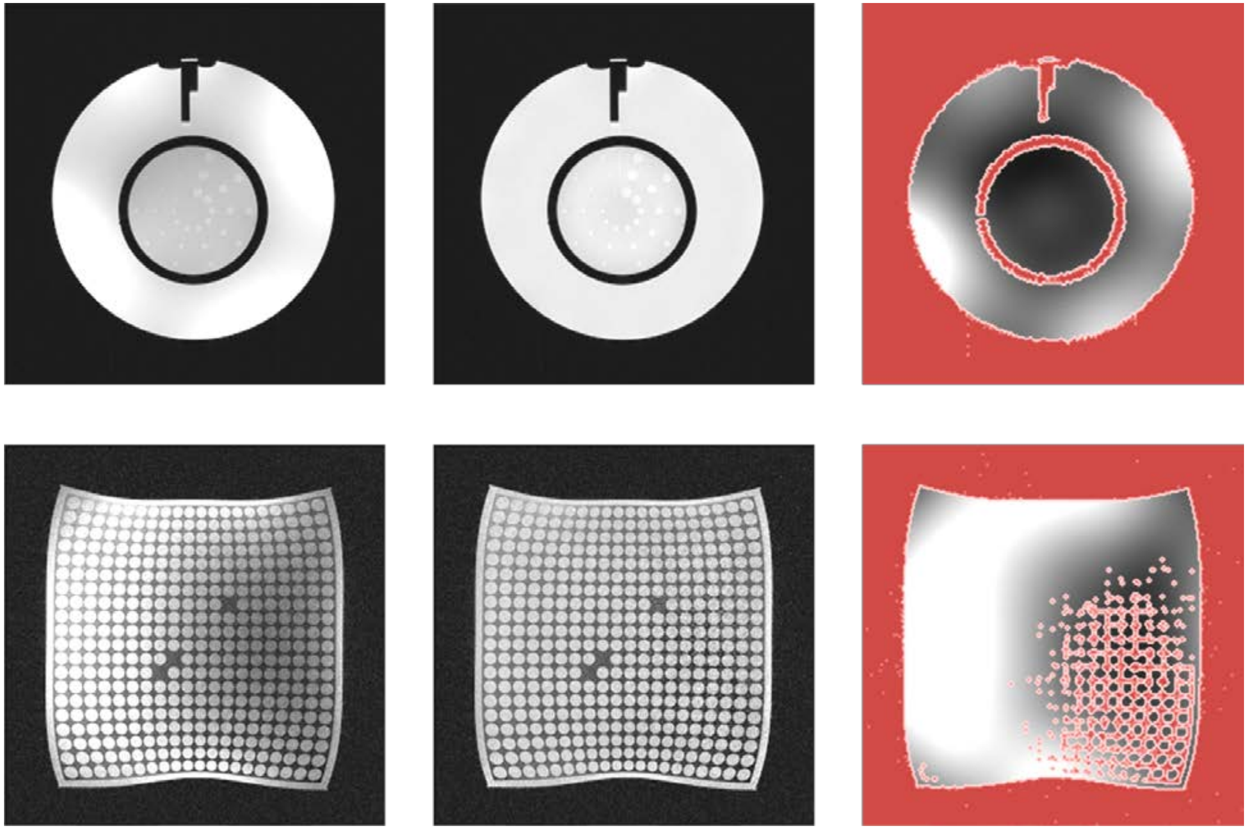
(a) MR image of a phantom
(b) ROI masked image

Experimental results

- Experimental conditions
  - Datasets
    - 2D MR phantom images and clinical images
    - Equipment: 3T MR scanner
    - Dimension: 256 x 256
  - Parameter setting
    - Bandwidth of estimated bias fields
      - $\xi < 10$, where ξ denotes the radial spatial frequency.
    - Number of parameters (DCT coefficient) to be obtain: 78

Experimental results

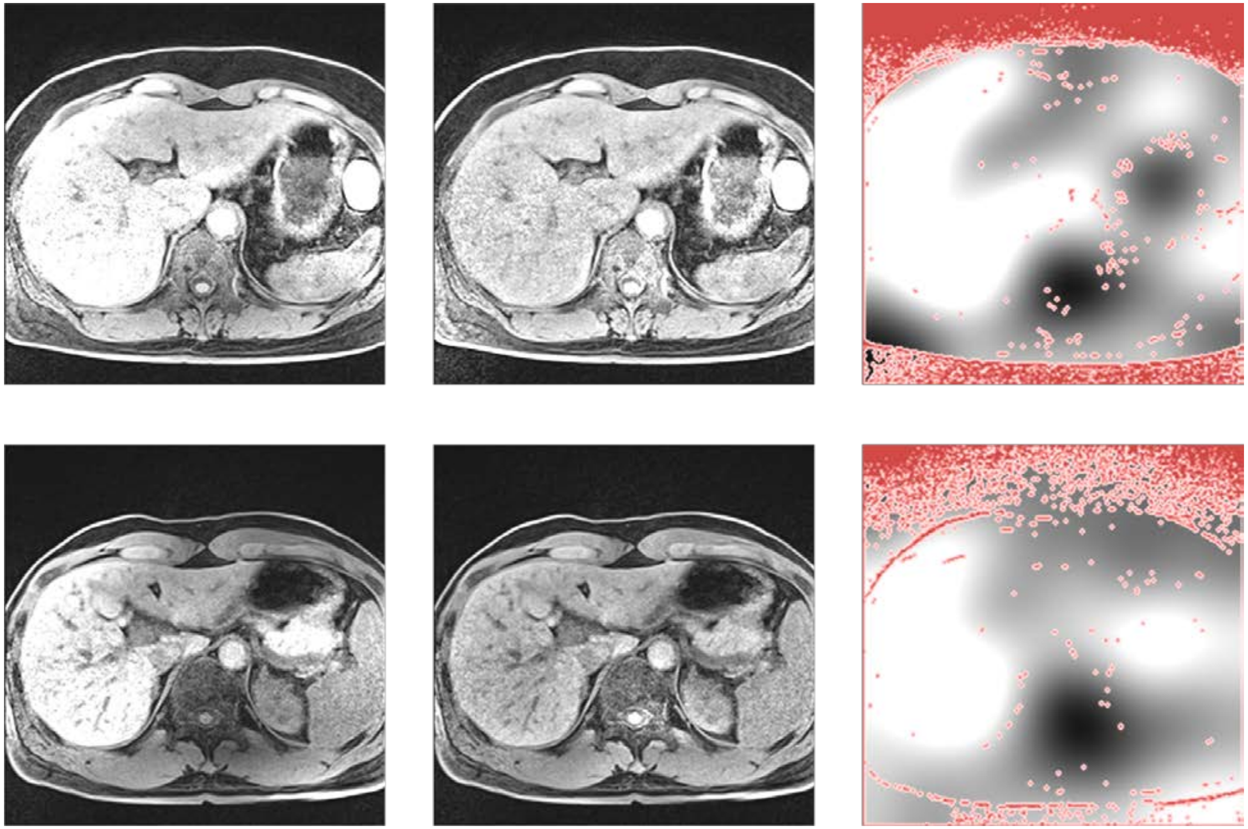
- Phantom data



Original image   Bias corrected image   Estimated bias field with ROI mask

Experimental results

- Clinical data



Original image | Bias corrected image | Estimated bias field with ROI mask

Conclusion

- Propose an algorithm for correcting intensity inhomogeneity in MR images by low frequency DCT coefficients optimization.
  - Image entropy based objective function
  - Downhill simplex as the optimization method
  - Multi-stage optimization to avoid local minima
  - ROI mask based on automatic thresholding

- Experiments and qualitative evaluation
  - Two 2D MR phantom images and two 2D abdominal MR images
  - Intensity homogeneity is well restored.
  - Small structures and edges are well preserved.

Thank you
for your attention.

Q & A