Bias Field Correction in MRI With Hampel Noise Denoising Diffusion Probabilistic Model

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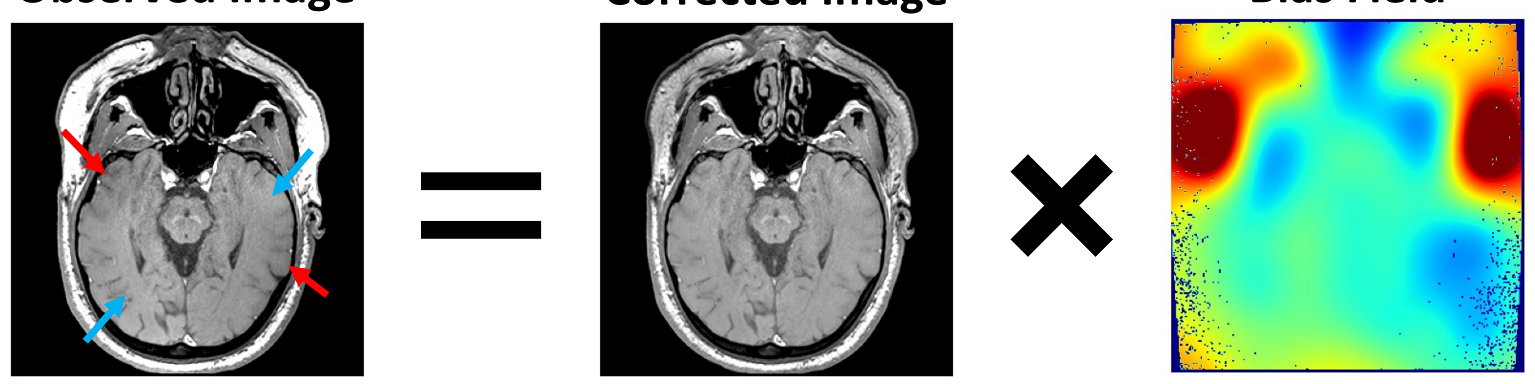
Introduction

- The bias field causes to reproduce and robustness to quantitative analysis.
  - ✓Bias field → *A slow varying multiplicative field*
  - ✓Intensity inhomogeneity by bias field → *same tissue, but different intensities*.
- N4 bias field correction *(Tustison, et al. IEEE TMI, 2010)* has been commonly used for bias field correction but has limitations.

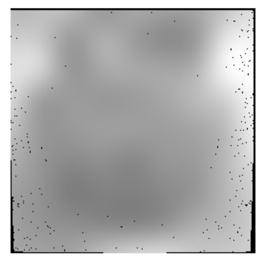
Observed Image | Corrected Image | Bias Field



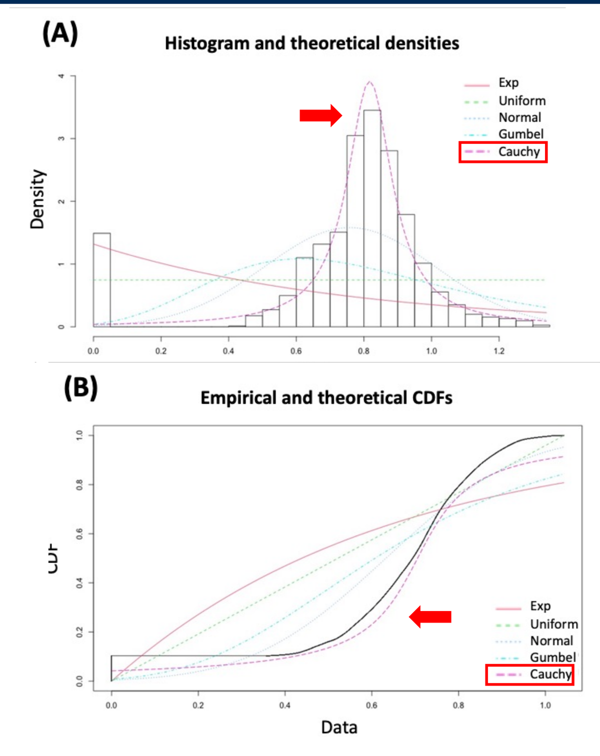
Theory

--- *Theory* ---

- The bias field map was analyzed to find a distribution that accurately represents its intensity.



Bias field map

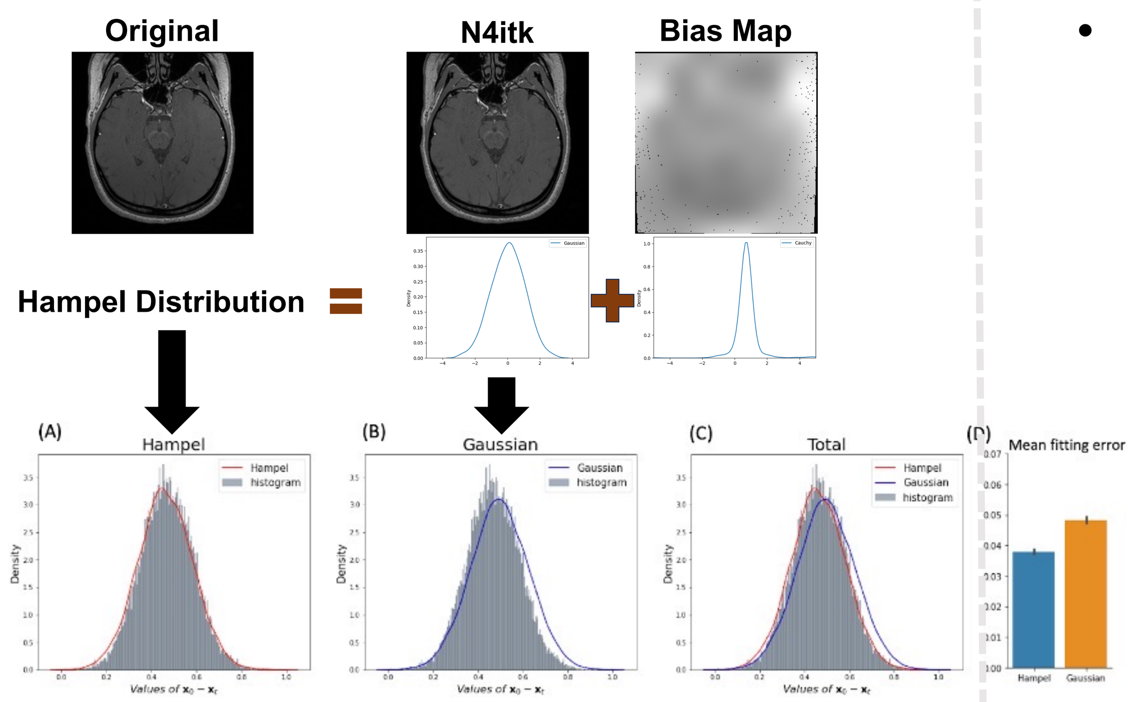


- ***The Cauchy-Lorentz distribution**** was discovered to be the best fit for describing the intensity of the bias field.

*** Cauchy-Lorentz Distribution:**

$$F_c(x; x_0, \gamma) = \frac{1}{\pi\gamma}\left[\frac{\gamma^2}{(x-x_0)^2+\gamma^2}\right] = F_c(x; \mathbf{0.6332}, \mathbf{0.0274})$$

- ***The Hampel mixture distribution**** represents disrupted image intensity.
- Mean fitting error between histogram and probability function is calculated. *The mean fitting error is lower in Hampel function compared to N4.*
- We propose ***Hampel Denoising Diffusion Model (HDDnet)*** conceived to model inhomogeneities by ***Cauchy-Lorentz distribution***



*** Hampel Distribution:**

$$F_h(x, \alpha) = (1-\alpha)F_n(x; 0, 1) + \alpha F_c(x; \mathbf{0.6332}, \mathbf{0.0274})$$

$$\mathrm{H}(\alpha, x_0, \gamma) = \mathrm{H}(\mathbf{1e-05}, \mathbf{0.6332}, \mathbf{0.0274})$$

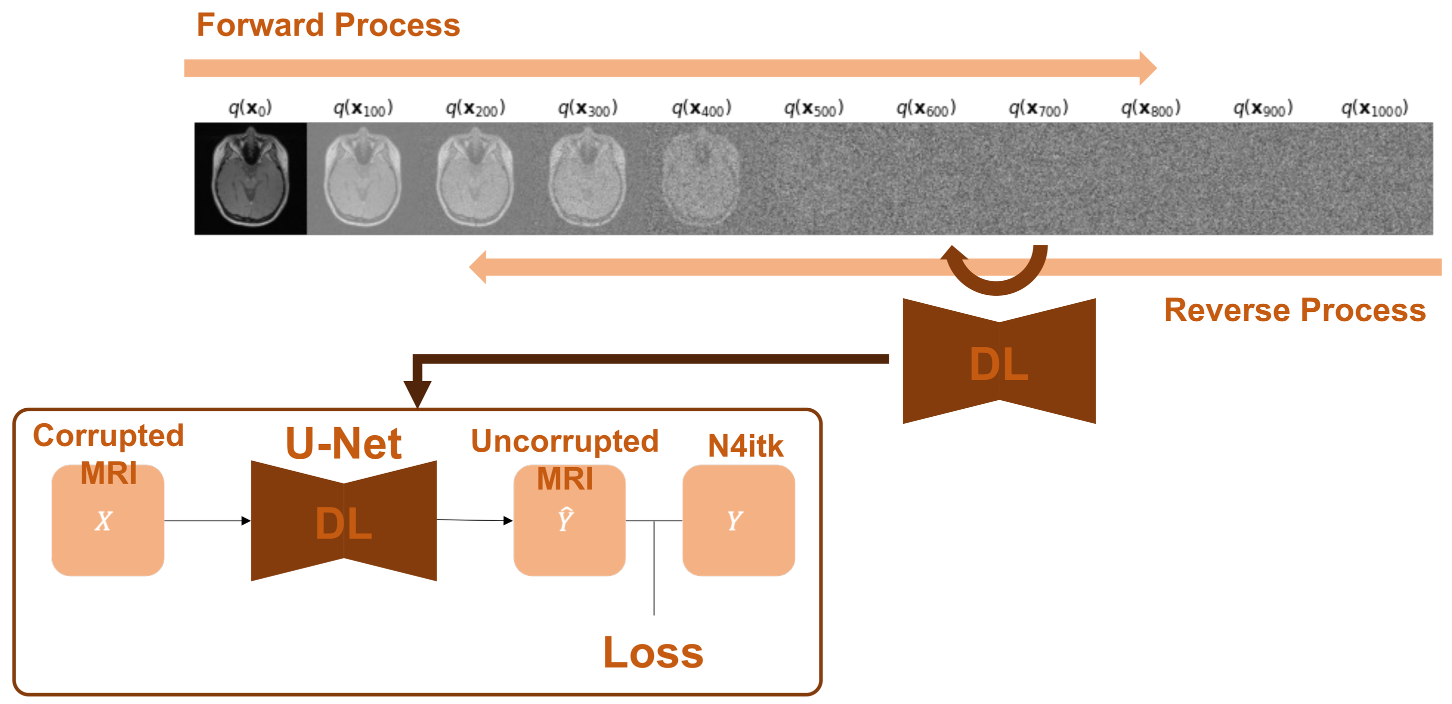
Methods

--- *Experiment* ---

[Dataset]

- Study included ***202 subjects.*** (126 male, 76 female, age 26.27±7.84 years)
- 3D gradient-echo sequence (GRE) with magnetization transfer (MT) pulses at 3T MRI.
- Ground truth dataset was constructed through ***N4 bias field correction***.

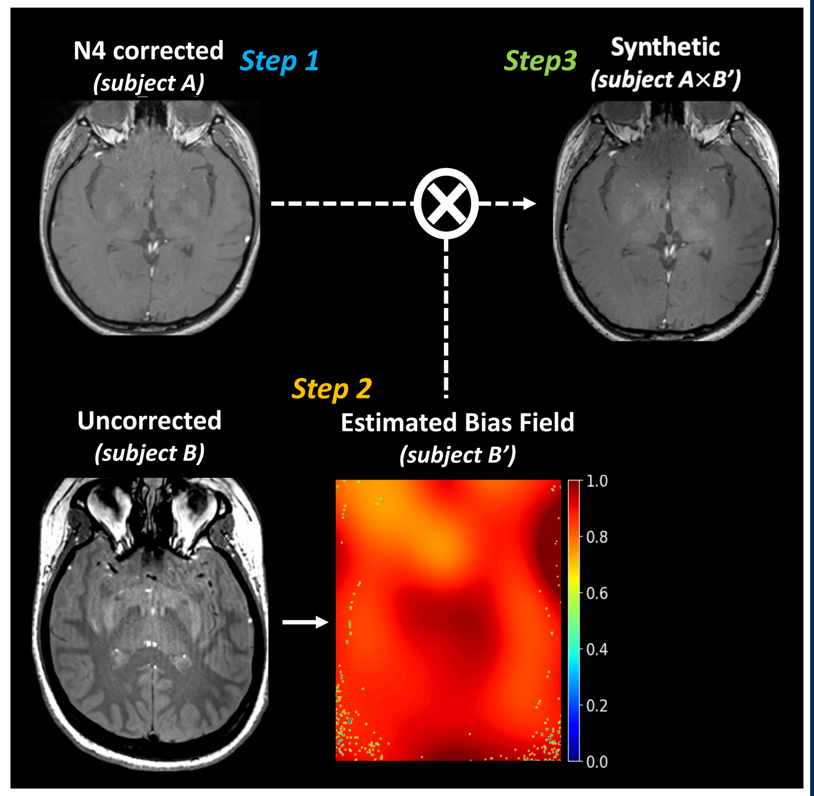
[Training]



- We used ***U-Net*** for training. (Detail; Adam, epoch 512, batch size 8, L2 loss, sigmoid)
- Loss function were calculated between the prediction images and ground truth from N4itk

[Evaluation]

- *Quantitative analysis*
  - MSE (Mean Squared Error)
  - PSNR (Peak Signal-to-Noise Ratio)
  - SSIM (Structural Similarity Index Measure)
  - Inference Time
- *Qualitative analysis*
  - using synthetic bias field image
    - ✓ Step1: Obtain the corrected image through N4 bias field correction. (subject A)
    - ✓ Step2: Obtain the estimated bias field (subject B') through N4 bias correction from the uncorrected data (subject B).
    - ✓ Step3: Multiplication (subject A×B') the N4 corrected image with estimated bias field



Results

[Quantitative analysis]

- HDDnet outperformed Gaussian random noise in terms of MSE, PSNR, and SSIM.

Distribution	MSE	PSNR	SSIM	Inference Time
Gaussian	0.0004 ± 0.0003	32.486 ± 2.649	0.950 ± 0.002	4.471 ± 0.030
Hampel	**0.0003 ± 0.0002**	**35.945 ± 1.050**	**0.983 ± 0.004**	**4.473 ± 0.012**

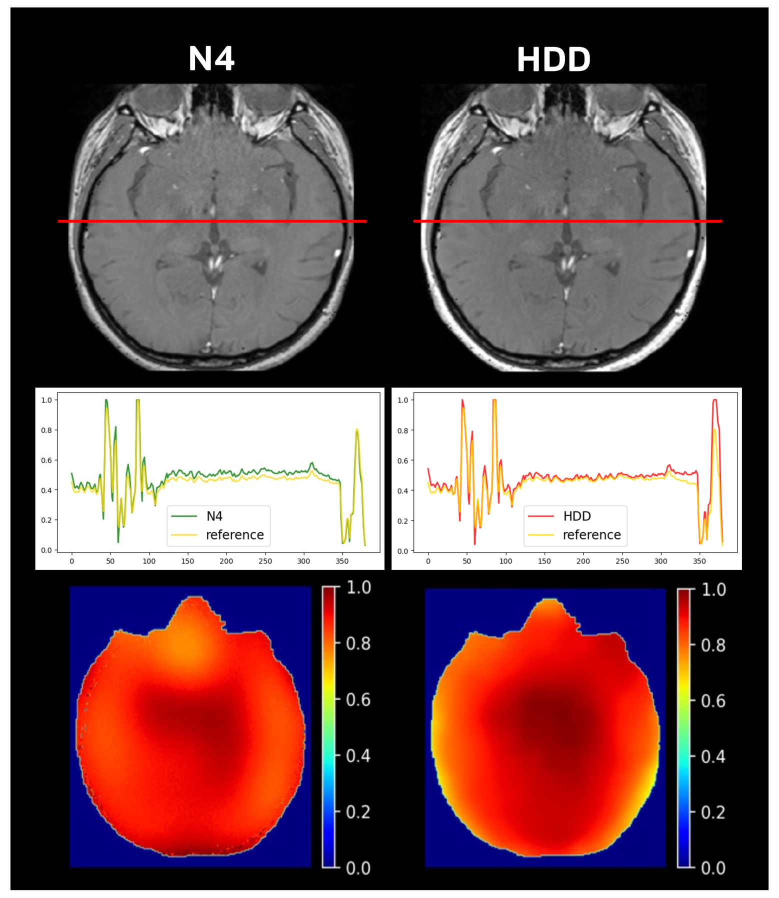
- HDDnet outperformed N4 bias field correction method in terms of MSE and PSNR, with a small difference in SSIM.
- N4 bias field correction method took an average of 39.601 seconds to correct the bias field in corrupted MRI, while HDDnet only took an average of 4 seconds, making it 9.75 times faster.

Method	MSE	PSNR	SSIM	Inference Time
HDDnet	**0.0001 ± 0.0002**	**36.865 ± 2.614**	0.978 ± 0.003	**4.473 ± 0.012**
N4	0.0003 ± 0.0003	34.766 ± 1.815	**0.979 ± 0.003**	39.601 ± 0.128

* HDDnet: Hampel distibution diffusion network

[Qualitative analysis]

- N4 and HDDnet exhibited a similar pattern of the bias field in synthetic images.



Discussion

[Summary]

- The proposed method involves replacing Gaussian noise with Hampel noise, a mixture of Gaussian and Cauchy-Lorentz distributions.
- The method offers improved robustness and automatic parameter settings compared to N4 for bias field correction.

[Limitation and Future work]

- Comparisons with other MR bias field correction methods need to be compared.
- The quantitative analysis should be conducted to verify the effectiveness of the proposed method.