MS Lesion Segmentation using FLAIR MRI only

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ABSTRACT

We present an efficient, unsupervised FLAIR-only MS lesion segmentation algorithm that does not use tissue priors or parametric models. An edge-based model of partial volume averaging (PVA) is used to estimate fuzzy membership profiles in order to map FLAIR graylevel to tissue class.

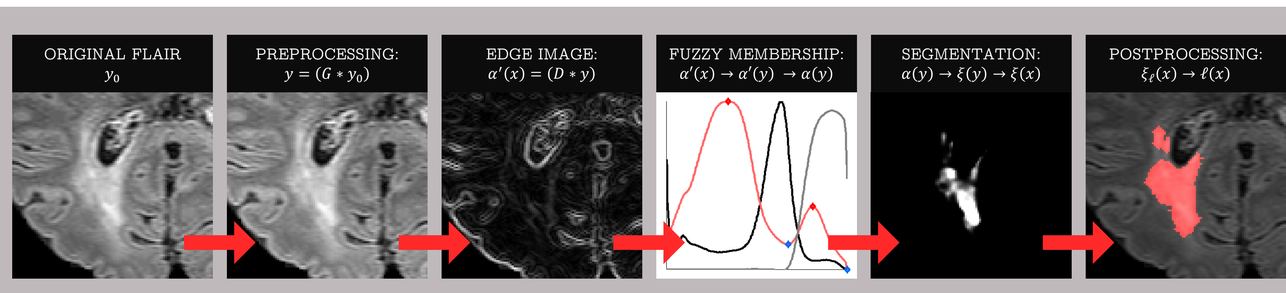
INTRODUCTION

Automated Segmentation of MS Lesions:

- Can improve speed, accuracy, and reproducibility
- Facilitates large, retrospective, and temporal studies

Approaches and Challenges to Automation:

- Parametric models & supervised classification:
  - Challenged by variability in anatomy, and lesion load, as well as MRI scanner and sequence parameters
  - Partial volume averaging (PVA) not adequately modeled
- If require multiple MRI modalities:
  - Need accurate registration
  - Additional scan time and cost
  - Limited retrospective image availability



MODEL CHARACTERISTICS

Advantages:

- Unimodal: FLAIR only
- Nonparametric: no assumed distributions
- Registration-free
- Sub-voxel precision
- Unsupervised

Assumptions / Requirements:

- Univariate separability in FLAIR *
- Bias corrected *
- Brain extracted
- Homogeneous lesion appearance

* future works to overcome these

EDGE-BASED PVA MODEL

Inspiration

- Image edges correspond to PVA-affected voxels: Figure 1.
- Edge is proportional to change in partial volume fraction (α)

Model of PVA Graylevels:

$$y_{ik}(x) = \alpha_{jk}(x) \times y_j(x) + \left(1 - \alpha_{jk}(x)\right) \times y_k(x) \quad \begin{cases} y_j(x) \sim p_j(y) \\ y_k(x) \sim p_k(y) \\ \alpha_{jk}(x) \in [0,1] \end{cases}$$

Estimation of Partial Volume Fraction (PVF)

We desire global estimate of PVF given graylevel: $\alpha(y)$

1. Estimate change in PVF in x domain using edge image:
$$\alpha'(x) \Leftarrow \left| \nabla_x (Y(x)) \right|$$
2. Migrate to the global y domain using the conditional expectation, with KS density estimator:
$$\alpha'(y) = p(\alpha'(x) = 1 \mid y)$$
3. Identify pure tissue classes $y_j, y_k, \ldots$ as minima in $\alpha'(y)$:

Figure 2: top

4. Integrate to between y_j and y_k to resolve $\alpha(y)$:
$$\alpha_{jk}(x) = \frac{\int_{y_k}^{y} \alpha'(y)dy}{\int_{y_k}^{y_j} \alpha'(y)dy}, \qquad y \in [y_k, y_j]$$

Figure 2: middle

5. Construct fuzzy membership profiles $\xi(y)$:
$$\xi(c_k|y) = \begin{cases} 0, & y \in [0, y_j) \\ \alpha_{jk}(y), & y \in [y_j, y_k) \\ 1, & y = y_k \\ 1 - \alpha_{jk}(y), & y \in (y_k, y_\ell] \\ 0, & y \in (y_\ell, y_{max}] \end{cases}$$

Figure 2: bottom

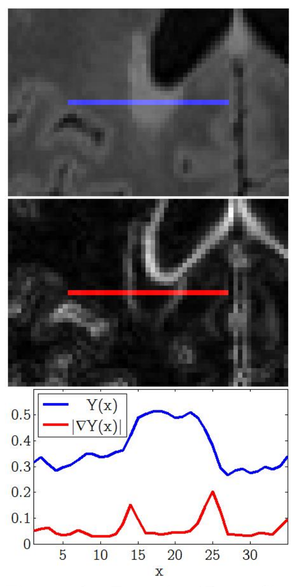


Figure 1. Example 1D profiles through FLAIR image Y(x) and edge image E(x) showing correlation of edge with change in PVF.

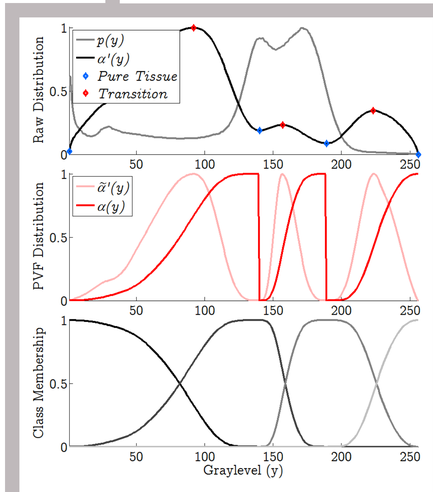


Figure 2. Graylevel distributions for one FLAIR; top – histogram $p(y)$ and distribution of edge $\alpha'(y)$; middle – normalized change in partial volume fraction $\tilde{\alpha}'(y)$ and partial volume fraction $\alpha(y)$; bottom – estimated tissue distributions $\xi(y)$, constructed from piecewise concatenation of $\alpha(y)$.

RESULTS

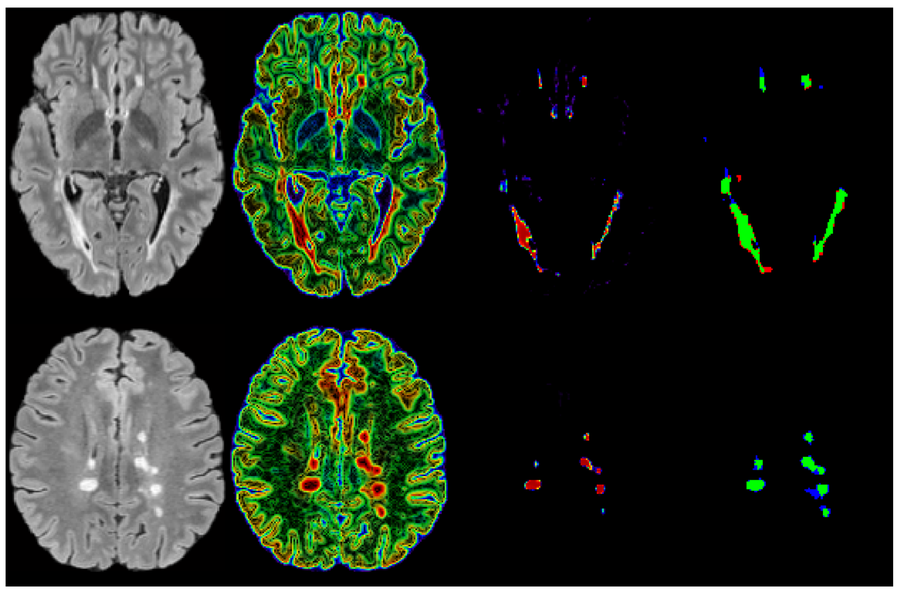


Figure 3. Example edge images and segmentations: (a) original FLAIR; (b) edge image with brightness depicting edge magnitude and pseudocolour depicting FLAIR graylevel (note orange PVA voxels); (c) pseudocolour initial fuzzy segmentation; (d) segmentation results, green is TP, red is FP, blue is FN.

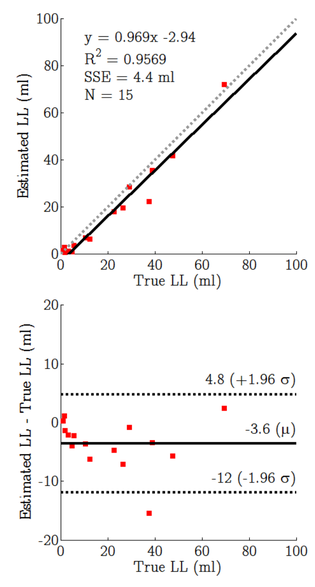


Figure 4. Bland-Altman plots showing good lesion volume agreement with expert segmentations, with a slight bias towards undersegmentation.

Segmentation Performance

- Mean DSC = 0.60 (all volumes)
  = 0.70 (lesion load > 5 ml)
- Mean PPV = 0.80; TPR = 0.53

ANCOVA:

- DSC correlated with lesion load (p = 0.013)
- DSC uncorrelated with scanner (p = 0.354)

Volume Agreement

- Pearson's $R^2 = 0.96$
- Undersegmentation bias (slope = 0.97)

Processing Speed

30 seconds per volume
(MATLAB R2016, Intel i7, 16GB RAM)

FUTURE WORKS

Local Analysis:

- Compute $\alpha'(y)$ locally (for each voxel), then estimate pure tissues graylevels $\bar{y}_c(x)$
- Estimate bias field from $\bar{y}_c(x)$ by fitting low order basis functions
- Overcome: (1) bias field, (2) overlapping graylevel distributions (bright GM)

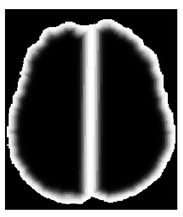
Defining "Pure Lesion"

- Small, inhomogeneous lesions have less prominent extrema in $\alpha'(y)$
- Multi-scale edge analysis could possibly resolve this

Prior-Free Ventricle Segmentation

- Flow-through artifacts could additionally be excluded

PRE- & POST-PROCESSING



Preprocessing

- Bias correction using SPM12: "Segment"
- Brain masks: provided by MSSEG Competition

Postprocessing

- Threshold fuzzy segmentation: $\xi(x) \geq \tau$
- Enforce minimum lesion size
- Distance from brain edge and midline (above left)

Region Growing

- Mimic radiologist: liberal lesion borders
- Compare candidate voxel at x^* to q^{th} quantile of y in initial segmentation A:

if: $\left| y(x^*) - Q_{y_{x \in S}}(q) \right| < \Psi$ **then**: $A \leftarrow A \cup x^*$

Parameter Optimization

- Objective: mean DSC
- Parameters:
  - Fuzzy threshold τ
  - FPR distances & minimum lesion size
  - Region growing parameters

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