EIT image reconstruction with L1 data and image norms

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Motivation

• In ICU, measurement errors unavoidable due to dynamics of human body.

• High contrast resolution are preferred to differentiate various tissue types.

• Before: one-step Gauss Newton method (L2 norm)
  – Smoothed edges
  – Sensitive to measurement errors (outliers)

• L1 norm solution:
  – **Image norm**: preserve edges (non-smooth optimization)
  – **Data norm**: robust against measurement outliers
• **Objectives:**
  - Robust algorithms in clinical setting

• **Approaches:**
  - Evaluation using experimental/clinical data
    • Human lung ventilation
    • Dog breathing data
  - 4 alternatives with L1 and L2 norms on data and image terms (L2L2, L2L1, L1L2, L1L1)
L2 norm for data misfit and image prior

- L2 norm - least square solution/Tikhonov
- L2 norm for the image prior term produces smoothed edges
- L2-norm for the data misfit is more sensitive to measurement outliers, as the differences between model and data are squared

\[
\arg\min_x \left\{ F(x) := \frac{1}{2} \| f(x) - y \|_{l_2}^2 + \frac{1}{2} \| Rx \|_{l_2}^2 \right\}
\]

Least square solution

Penalty term
L1-L2 norms for data misfit and image prior

- **PDIPM** - Primal Dual Interior Point Framework

\[
\arg\min_x \left\{ \mathcal{F}(x) := \|f(x) - y\|_p^p + \|\lambda R(x - x_0)\|_n^n \right\}
\]

- **L1 norm solution**
  - **L1 norm** - sum(abs(.))
  - Data 1-norm reduces the penalty for outliers
  - Image 1-norm preserves edges and allows sharp images
  - Computationally more complex
Hyperparameter Estimation (L-curve)

- L-curve based automatic parameter estimation for all L1/L2 combinations

No noise

\[ \log ||Rx||_2 \]

\[ \log ||f(x)-y||_2 \]
Results 1: Simulation

<table>
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<tr>
<th>p, n</th>
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<th>1, 2</th>
<th>2, 1</th>
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<tbody>
<tr>
<td>A</td>
<td><img src="image1.png" alt="Image A" /></td>
<td><img src="image2.png" alt="Image B" /></td>
<td><img src="image3.png" alt="Image C" /></td>
<td><img src="image4.png" alt="Image D" /></td>
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<tr>
<td>B</td>
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<td><img src="image6.png" alt="Image B" /></td>
<td><img src="image7.png" alt="Image C" /></td>
<td><img src="image8.png" alt="Image D" /></td>
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<td>C</td>
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<td>D</td>
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<td><img src="image15.png" alt="Image C" /></td>
<td><img src="image16.png" alt="Image D" /></td>
</tr>
</tbody>
</table>

No noise, No outliers

Noise, (40 dB) No outliers

No noise, outliers

Noise, outlier
Experimental Protocol– Human Ventilation

• PEEP – Positive end-expiratory pressure
• Experimental Protocol consisted of:
  – Baseline ventilation stage
  – Lung recruitment stage (increased airway pressure): R1 – R4
  – PEEP titration stage (decreased airway pressure): T1–T4
• Goe-MT II EIT device (CareFusion, Hoechberg, Germany)
Results 2: Human Lung Ventilation
Results 2: Human Lung Ventilation
Results 3: Dog breathing data

Reconstructed images of anaesthetized and ventilated dog

- Known electrode errors in the data
- $L_2L_2$ is suffered the most from the electrode noise
- $L_1L_1$ is the best candidate with less artifact
Discussion

• L1 norm is robust against data errors
• L1 norm for the data misfit provided clinically relevant information under electrode error
• Blocky L1 image norm is not necessarily good

😍
• L1 norm is computationally expensive
• Code is publicly available under EIDORS