WEIGHTED L1 AND L2 NORMS FOR IMAGE RECONSTRUCTION: FIRST CLINICAL RESULTS OF EIT LUNG VENTILATION DATA

PRESENTER:

PEYMAN RAHMATI,
PHD CANDIDATE,
Biomedical Eng., Dept. of Systems and Computer Eng.,
Carleton University, Ottawa, ON., Canada.

Supervisor:
Professor Andy Adler

April 2013
INDEX

- Motivation (objectives, problem statement, and solution)

- Traditional Image Reconstruction Algorithm (advantage and disadvantages)

- Proposed Image Reconstruction Algorithm (Weighted L1 and L2 norms)

- Electrical Impedance Tomography (EIT)

- Simulated and clinical results (EIT human lung data)

- Conclusion
IMAGING MODALITY (ELECTRICAL IMPEDANCE TOMOGRAPHY (EIT))

- EIT is a medical imaging modality in which an image of the internal conductivity/permittivity distribution of the body is reconstructed from boundary electrical measurements.

- In a typical EIT system, one pair of electrodes injects low frequency current to the medium and the other pairs of the electrodes collect the difference voltage on the surface of the medium.
**Motivation**

- **Objectives:**
  Robust reconstruction algorithms to *spatial noise* and *data outliers* for the clinical applications, which is EIT human breathing data in this study.

- **Problem:**
  EIT image reconstruction in ICU is challenging because the presence of measurement errors due to dynamics of human body.

- **Solution:**
  High contrast image reconstruction is preferred to differentiate various tissue types.
TRADITIONAL IMAGE RECONSTRUCTION ALGORITHM

We need to minimize the above error function to find the best estimate of x, which is the solution of inverse problem.

Error function:

\[
\arg \min_x \{ \Delta x = \| f(x) - y \|_m^m + \| \lambda R(x - x_0) \|_n^n \}
\]

where
- \( m, n = 1 \) (L1 norm) or 2 (L2 norm),
- \( f(x) \) is measured data,
- \( y \) is real data,
- \( x \) is pixel illumination,
- \( x_0 \) is expected pixel illumination.
- \( R \) is regularization matrix,
- \( \lambda \) is the regularization factor.
TRADITIONAL IMAGE RECONSTRUCTION METHOD

One-step Gauss Newton method (L2 norm)

Advantage:

– Simple to implement,

Drawbacks:

– Smoothed edges,
– Sensitive to measurement errors (noise+outliers).
PROPOSED IMAGE RECONSTRUCTION METHOD

Image Reconstruction using weighted L1 and L2 norms

Error function:

\[
\arg \min_x \{ \Delta x = \xi \| f(x) - y \|_1^1 + (1 - \xi) \| f(x) - y \|_2^2 + \\
\eta \| \lambda R(x - x_0) \|_1^1 + (1 - \eta) \| \lambda R(x - x_0) \|_2^2 \} \]

where \( \xi \) and \( \eta \) are weighting parameters within the range \([0,1]\).

Question to answer:

How different selection of weighting parameters affects the reconstructed image?
PROPOSED IMAGE RECONSTRUCTION METHOD

Advantages:
– The weighted L1 and L2 norms can be independently applied over the data mismatch and the regularization terms (image term) of an inverse problem.
– Preserve edges (non-smooth optimization ),
– Robust against measurement errors (noise+outliers).

Difficulty:
– Computationally more expensive than the GN method.
  GN                             3-5 iterations
  Proposed method               10-15 iterations
EVALUATION OF THE PROPOSED RECONSTRUCTION METHOD

Using simulated data

- 16 different selection of weighting parameters
  16 different reconstructed images.

Using clinical data

- Human lung ventilation data,
<table>
<thead>
<tr>
<th>ξ</th>
<th>0</th>
<th>0.3</th>
<th>0.6</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>η</td>
<td>0</td>
<td>0.3</td>
<td>0.6</td>
<td>1</td>
</tr>
<tr>
<td>L2-L2</td>
<td>(0.3<em>L1+0.7</em>L2+L2)</td>
<td>(0.6<em>L1+0.4</em>L2+L2)</td>
<td>L1-L2</td>
<td></td>
</tr>
<tr>
<td>(L2+0.3<em>L1+0.7</em>L2)</td>
<td>?</td>
<td>?</td>
<td>?</td>
<td></td>
</tr>
<tr>
<td>(L2+0.6<em>L1+0.4</em>L2)</td>
<td>?</td>
<td>?</td>
<td>?</td>
<td></td>
</tr>
<tr>
<td>L2-L1</td>
<td>(0.3<em>L1+0.7</em>L2+L1)</td>
<td>(0.6<em>L1+0.4</em>L2+L1)</td>
<td>L1-L1</td>
<td></td>
</tr>
<tr>
<td>?</td>
<td>?</td>
<td>?</td>
<td>?</td>
<td></td>
</tr>
</tbody>
</table>
EIT SIMULATED DATA

No noise and data outliers

16 different combination of weighting parameters

\(|\xi\| \begin{array}{cccc}
0 & 0.3 & 0.6 & 1 \\
0  &  &  & \\
0.3 &  &  & \\
0.6 &  &  & \\
1   &  &  & 
\end{array} |
EIT SIMULATED DATA

Added zero-mean Gaussian noise (-60 dB) to the measured data.

\[
[\zeta, \eta] = [0, 0] \quad [\zeta, \eta] = [0, 0.3] \quad [\zeta, \eta] = [0, 0.6] \quad [\zeta, \eta] = [0, 1]
\]

\[
[\zeta, \eta] = [0.3, 0] \quad [\zeta, \eta] = [0.3, 0.3] \quad [\zeta, \eta] = [0.3, 0.6] \quad [\zeta, \eta] = [0.3, 1]
\]

\[
[\zeta, \eta] = [0.6, 0] \quad [\zeta, \eta] = [0.6, 0.3] \quad [\zeta, \eta] = [0.6, 0.6] \quad [\zeta, \eta] = [0.6, 1]
\]

\[
[\zeta, \eta] = [1, 0] \quad [\zeta, \eta] = [1, 0.3] \quad [\zeta, \eta] = [1, 0.6] \quad [\zeta, \eta] = [1, 1]
\]
EIT SIMULATED DATA

Zero-mean Gaussian noise (-60 dB) and strong data outliers.
EIT Clinical data

Patient with healthy lungs
EIT CLINICAL DATA

Patient with Acute Lung Injury (ALI)
CONCLUSION

- We discuss the effectiveness of 16 different combinations of weighted norms (L1 and L2 norms) under two different measurement conditions (added noise and outliers) over EIT simulated data. The weighted L1 and L2 norms provide higher robustness against noise and outliers for bigger values of weighting parameters.

- We applied the weighted L1 and L2 norms on EIT clinical data, resulting in physiologically plausible results.

- The implementation of the weighted L1 and L2 norms is publicly available under EIDORS website.

- The L1 norm minimization is computationally expensive.
THANK YOU