Weighted L1 and L2 Norms for Image Reconstruction: First Clinical Results of EIT Lung Ventilation Data

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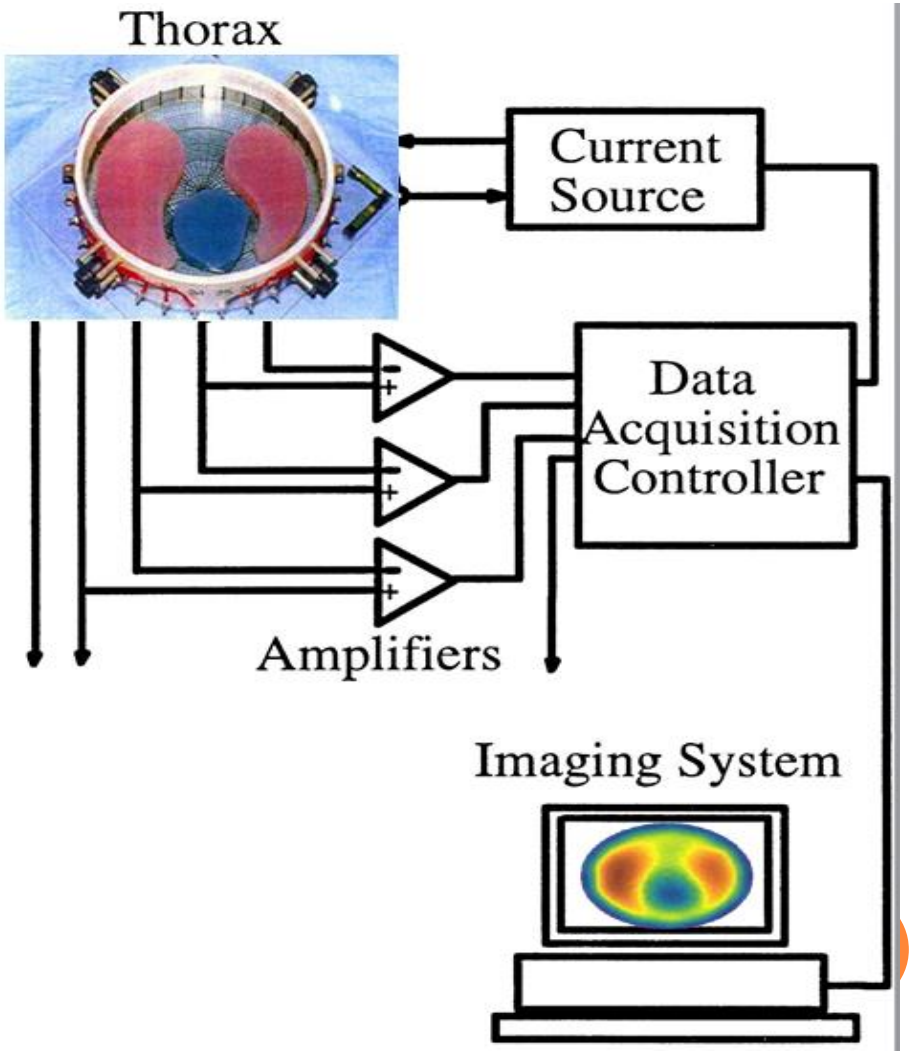
Imaging Modality (Electrical Impedance Tomography (EIT))

- 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:

Data mismatch term

Image mismatch term

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

where

- m, n =1 (L1 norm) or 2 (L2 norm) ,
- f(x) is measured data,
- y is real data,
- x is pixel illumination,
- x0 is expected pixel illumination.
- R is regularization matrix,
- λ 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:

Weighted L1 norm based Data Term

Weighted L2 norm based Data Term

$$\arg\min_x \{\Delta x = \zeta \left| f(x) - y \right|_1^1 + (1-\zeta) \left\| f(x) - y \right\|_2^2 +$$

$$\eta \left| \lambda R(x - x_0) \right|_1^1 + (1-\eta) \left\| \lambda R(x - x_0) \right\|_2^2 \}$$

Weighted L1 norm based Image Term

Weighted L2 norm based Image Term

where ξ and η 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,

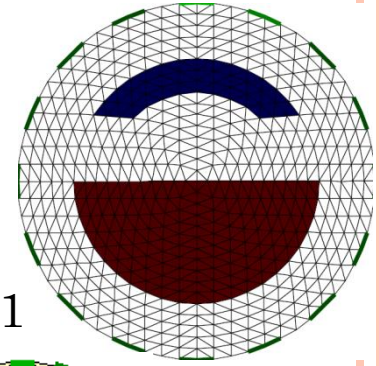
Evaluation Framework

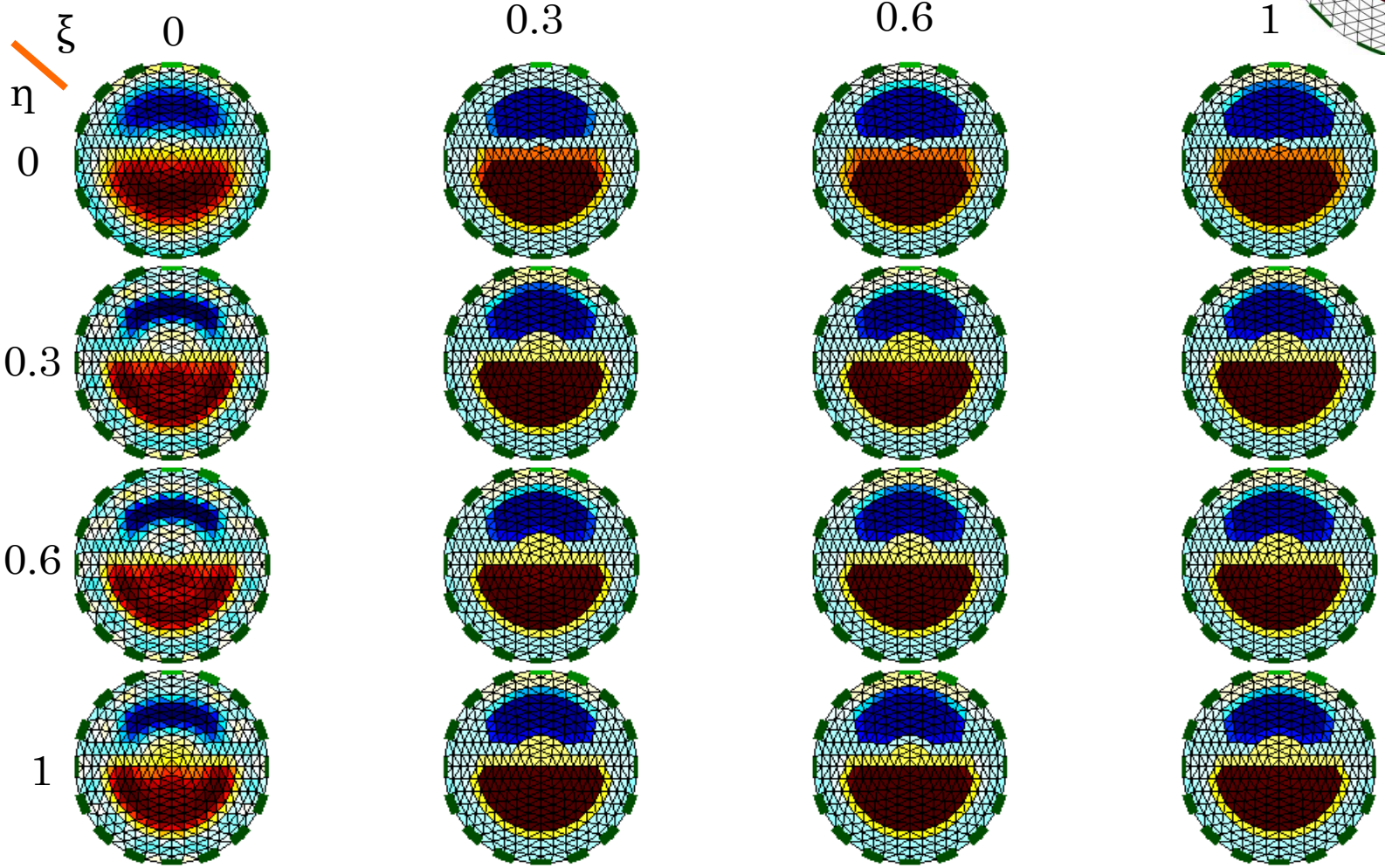
η \ ξ	0	0.3	0.6	1
0	L2-L2	(0.3*L1+0.7*L2+L2) ?	(0.6*L1+0.4*L2+L2) ?	L1-L2
0.3	(L2+0.3*L1+0.7*L2) ?	(0.3*L1+0.7*L2+0.3 *L1+0.7*L2) ?	(0.6*L1+0.4*L2+0.3 *L1+0.7*L2) ?	(L1+0.3*L1+0.7*L2) ?
0.6	(L2+0.6*L1+0.4*L2) ?	(0.3*L1+0.7*L2+0.6 *L1+0.4*L2) ?	(0.6*L1+0.4*L2+0.6 *L1+0.4*L2) ?	(L1+0.6*L1+0.4*L2) ?
1	L2-L1	(0.3*L1+0.7*L2+L1) ?	(0.6*L1+0.4*L2+L1) ?	L1-L1

EIT Simulated data

No noise and data outliers

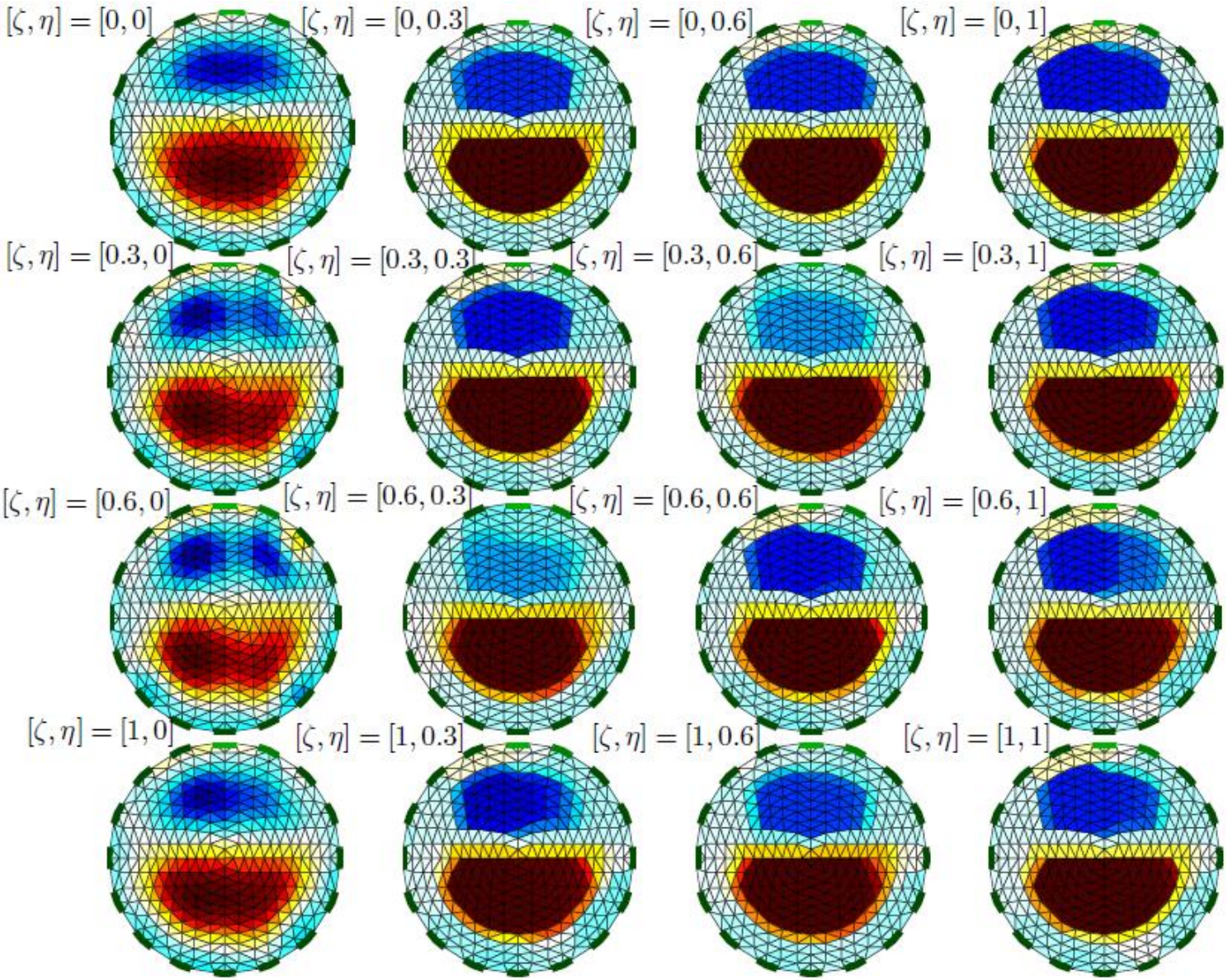
16 different combination of weighting parameters





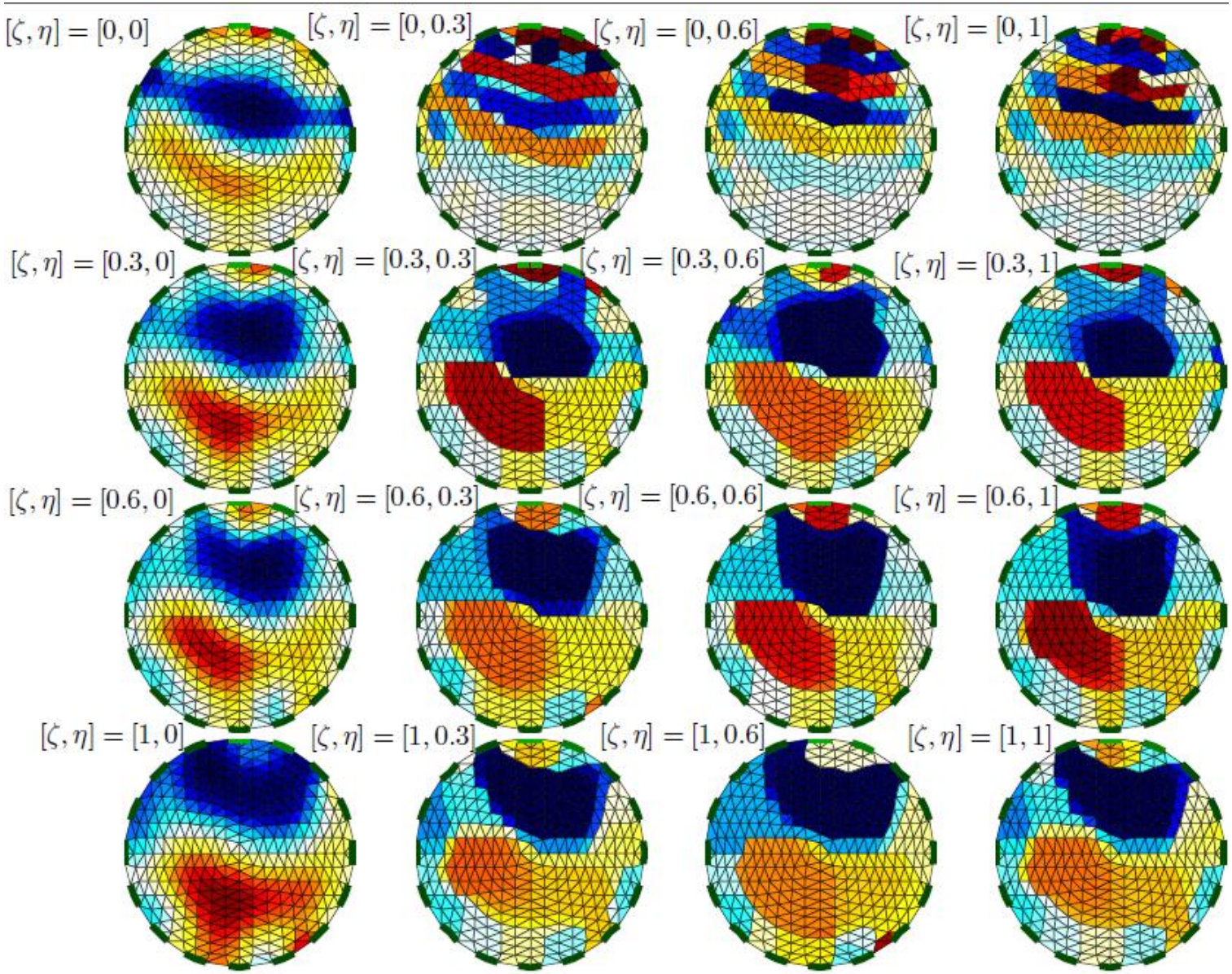
EIT Simulated data

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



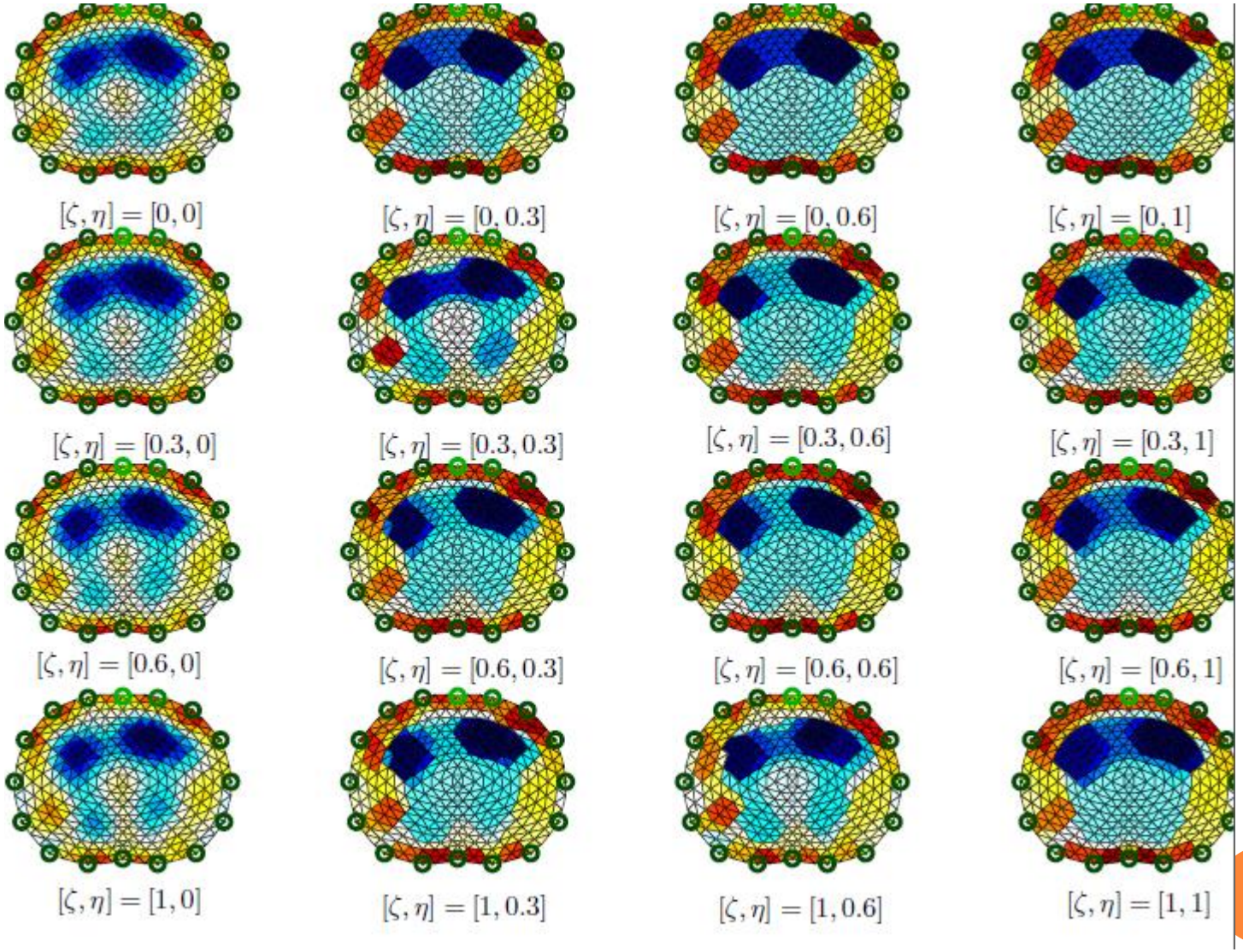
EIT Simulated data

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



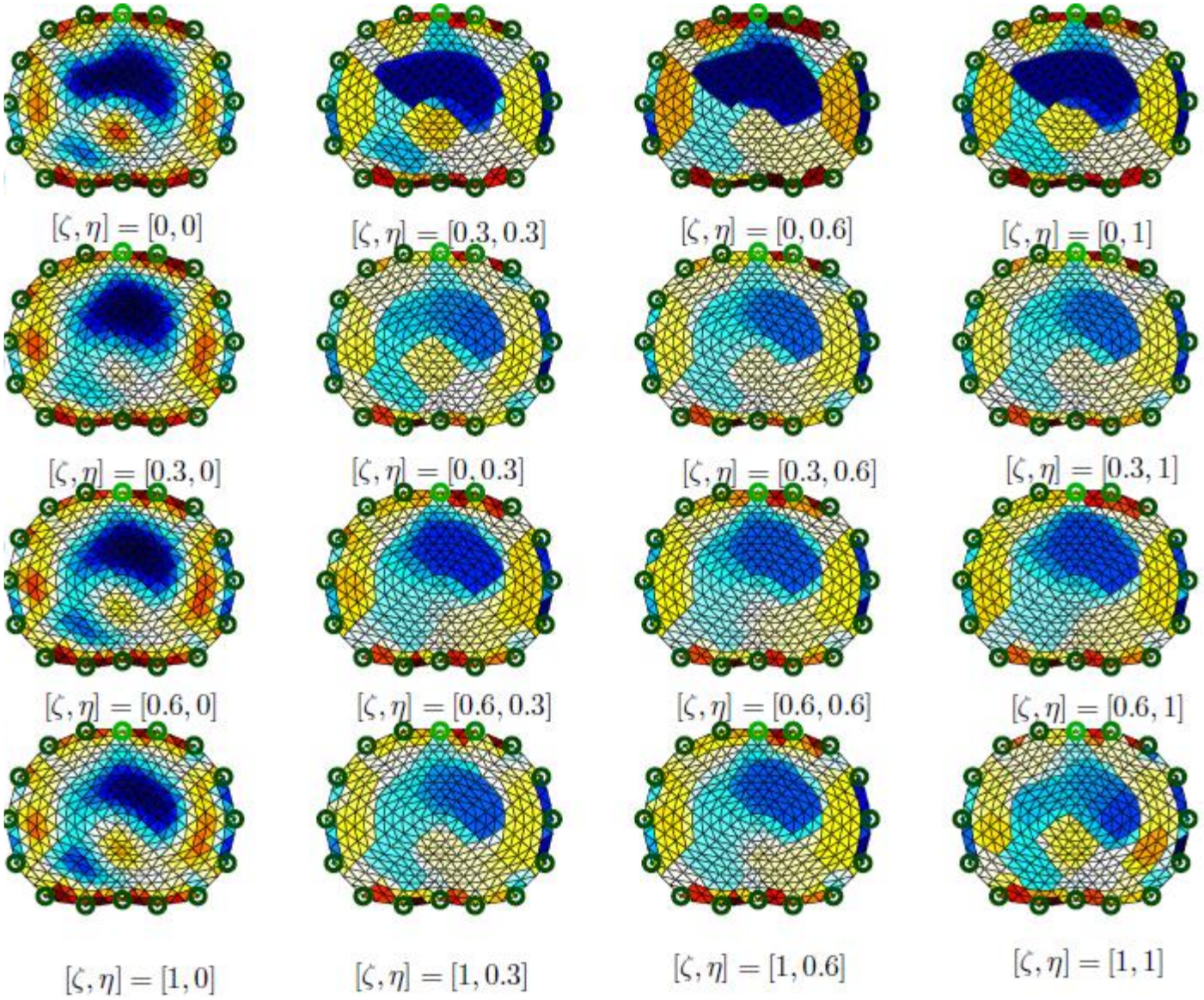
EIT Clinical data

Patient with healthy lungs



EIT Clinical data

Patient with Acute Lung Injury (ALI)



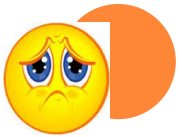
CONCLUSION

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

- We applied the weighted L1 and L2 norms on EIT clinical data ⟹ 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