Robust Stimulation and Measurement Patterns in Biomedical EIT

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Problem

The quality of images produced in impedance imaging is directly affected by the signal-to-noise ratio of the measurements and electrode connectivity.

In some scenarios, image quality can be improved by increasing the stimulation amplitude or reacquiring data. Stimulation amplitude is finite due to equipment properties. Additional electrical safety concerns exist in biomedical applications where high current densities can result in tissue heating and interference with the body's electrical systems. Reacquiring missing data may not be possible due to the cost of a study or the transient nature of the events being observed.

In these situations, we would like to utilize stimulation and measurement patterns that provide a robust data set in terms of good distinguishability throughout the imaged region despite the possibility of an a priori unknown set of poorly connected electrodes.

Distinguishability

dis·tin·guish·a·bil·i·ty *adjective*

the ability to distinguish between a hypothesis H_1 (conductivity change) and the null hypothesis H_0 (no conductivity change) within a particular Region of Interest (ROI) according to a measure m [2] determined by the z-score

$$z = \frac{\hat{m} - m_0}{\mathrm{std}(m)} = \frac{A_R \Delta\hat{\sigma}_R}{\left(\mathbf{R}_R \Sigma_n \mathbf{R}_R^{\intercal}\right)^{1/2}} = A_R \Delta\hat{\sigma}_R \sqrt{\mathbf{J}_R^{\intercal} \Sigma_n^{-1} \mathbf{J}_R} \qquad (1)$$

where $\hat{m}$ is the maximum likelihood estimate for m, the null hypothesis is m_0 and $\mathrm{std}(m)$ is the standard deviation of m. The measure m is the estimated impedance change $\Delta\hat{\sigma}$ in a region for a set of difference measurements.

Linear Programming

An optimal stimulation and measurement criteria is the primal maximin criteria

$$\hat{\mathbf{x}} = \max_{\mathbf{x}} \min_{\mathbf{y}} \mathbf{y}^{\intercal}\mathbf{A}\mathbf{x} \qquad \text{(primal)} \qquad (2)$$

where $\mathbf{A}$ is a matrix of distinguishabilities z. We wish to find the best stimulation and measurement strategy $\mathbf{x}$ that will maximize distinguishability z given the ROIs $\mathbf{y}$ that provide minimum distinguishability.

This can be solved through linear programming

$$\min_{\mathbf{y}} \mathbf{y}^{\intercal}\mathbf{A}\mathbf{x} = \min_{i} \mathbf{e}_i^{\intercal}\mathbf{A}\mathbf{x} \rightarrow v \leq \mathbf{e}_i^{\intercal}\mathbf{A}\mathbf{x}$$

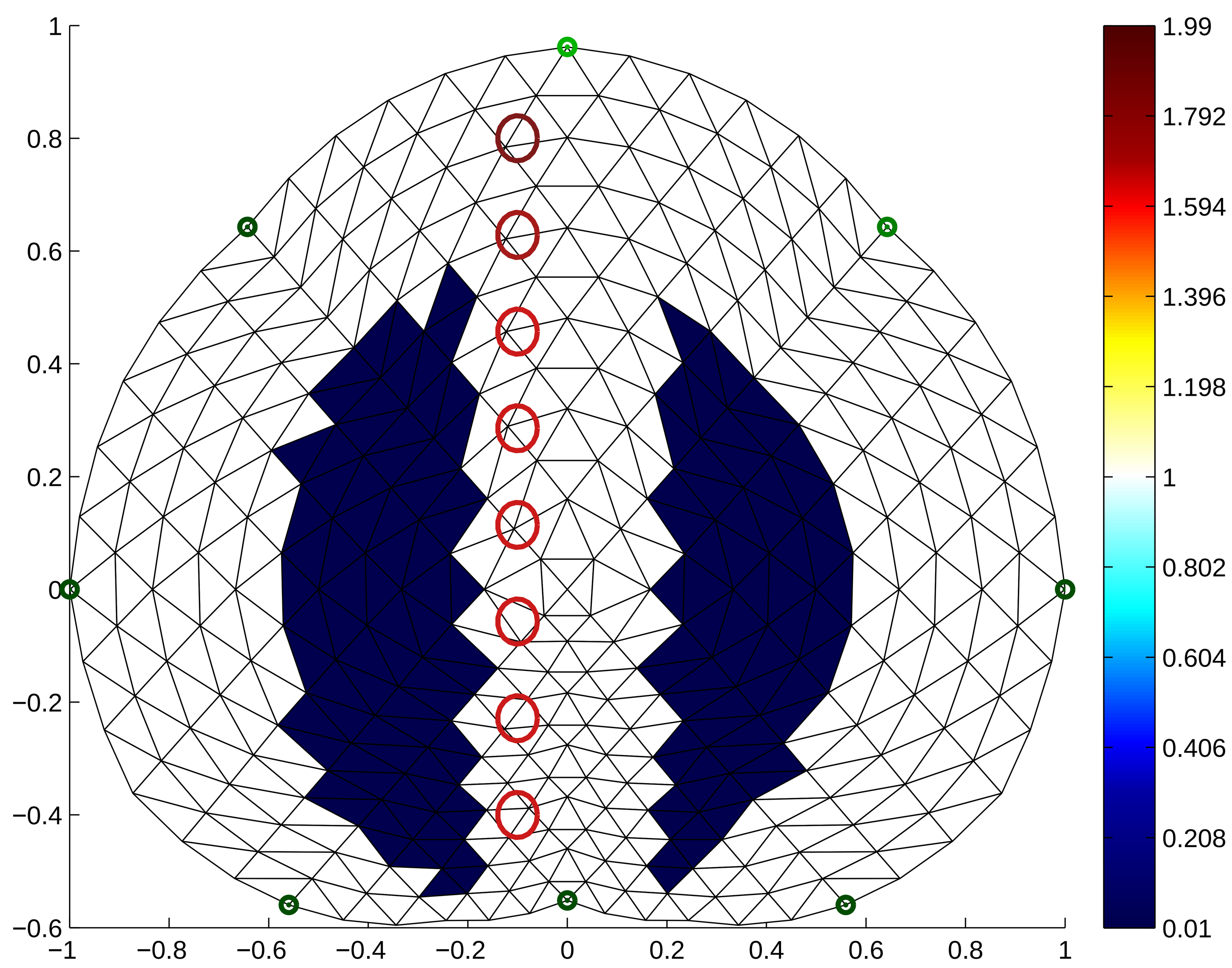
$$\max_{\mathbf{x}} \min_{\mathbf{y}} \mathbf{y}^{\intercal}\mathbf{A}\mathbf{x} \rightarrow \max v \qquad (3)$$

such that $v\mathbf{e} - \mathbf{A}\mathbf{x} \leq 0$; $\mathbf{e}^{\intercal}\mathbf{x} = 1$; $\mathbf{x} \geq 0$.

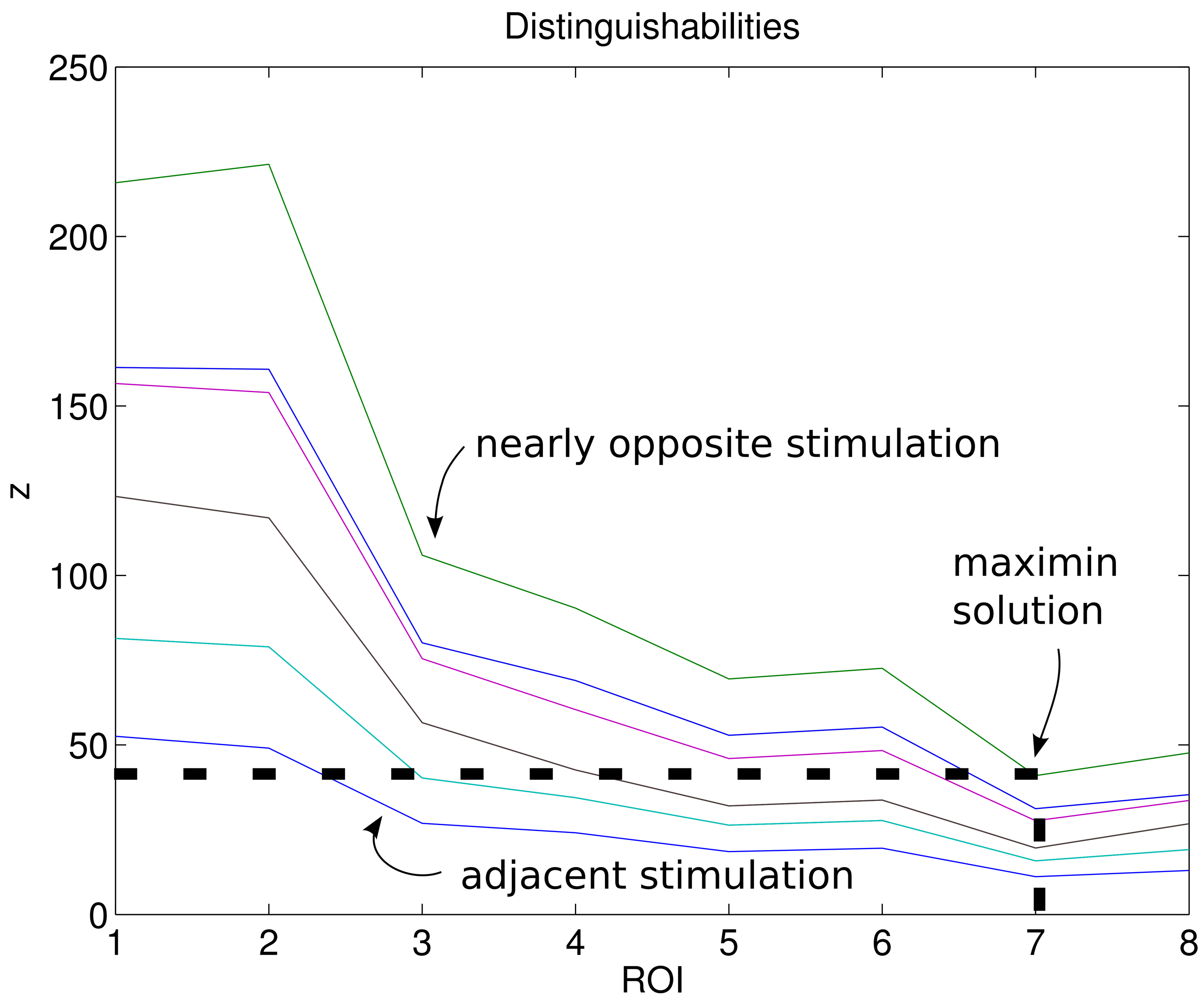
In matrix form with $\mathbf{x} \geq 0$ and v free, solve

$$\begin{bmatrix} -\mathbf{A} & \mathbf{e} \\ \mathbf{e}^{\intercal} & 0 \end{bmatrix} \begin{bmatrix} \mathbf{x} \\ v \end{bmatrix} \begin{matrix} \leq \\ = \end{matrix} \begin{matrix} 0 \\ 1 \end{matrix} \qquad (4)$$

Results



Left Figure: FEM mesh used for simulations; ROI as red circles with darkest circle as ROI#1; central ROIs have lower distinguishability



Right Figure: Distinguishability z for various stimulation and measurement strategies from adjacent (light purple: universally lowest z) to nearly opposite (light green: universally highest z)

In this work, we develop an approach to determine an optimal stimulation and measurement pattern for a particular arrangement of electrodes and subject.

The *distinguishability* over a set of regions of interest due to a variety of individual stimulation and measurement patterns is determined. Based on the calculated distinguishabilities of these candidate stimulation and measurement patterns, an optimal subset is selected through a *linear programming* formulation. The resulting selection is constrained so that reconstructed images avoid worst-case artifacts in the event of missing or poor quality data on particular channels.

The results were evaluated on two-dimensional simulations of the human thorax showing an acceptable quality of reconstruction using the selected stimulation and measurement patterns.

References

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[3] Adler A, Lionheart WRB, 2006 Uses and abuses of EIDORS: an extensible software base for EIT, *Physiol. Meas.* 27 S25

[4] Isaacson D 1986 Distinguishability of conductivities by electric current computed tomography, *IEEE Trans. Med. Imaging* 5 91–5

Discussion

This work demonstrates the use of linear programming to select the optimal stimulation and measurement patterns for a given geometry and conductivity distribution based on the distinguishability of conductivity changes within specified ROIs.

This work can be extended to robust stimulation patterns by first selecting an optimal set of stimulation patterns, then removing an electrode and repeating the process. The distinguishability and linear programming algorithm was demonstrated on arbitrary domains with arbitrary initial conductivity distributions.

In summary, this work provides a practical algorithm for selecting appropriate and robust stimulation and measurement patterns on arbitrary domains.