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Multiple measurement vector based image reconstruction for multi-frequency impedance imaging using capacitive sensor

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Abstract: A multiple measurement vector (MMV) model based image reconstruction algorithm is proposed to reconstruct simultaneously conductivity and permittivity distribution based on multi-frequency and complex-valued electrical capacitance tomography (ECT) data. Alternating direction method of multipliers (ADMM) is applied to solve the multi-frequency image reconstruction problem.

1 Introduction

Traditional ECT model and corresponding image reconstruction algorithms can only reconstruct permittivity distribution at a single frequency [1]. Some recent work has demonstrated the concept of complex-valued multi-frequency ECT in simulation, which can, in theory, reconstruct distributions of permittivity and conductivity simultaneously by using non-invasive capacitive sensors [2]. This paper further explores the practical feasibility to perform simultaneous reconstruction of permittivity and conductivity based on experimental data. A MMV model based image reconstruction algorithm is proposed to improve reconstruction quality by utilising spatial and frequency correlations of multi-frequency images.

2 Methods

A complex-valued ECT forward model is firstly established in Eq. (1) to describe the relation of the complex-valued capacitance measurement and the distribution of permittivity and conductivity.

$$\begin{bmatrix}\Delta C_r\\ \Delta C_i\end{bmatrix} = \begin{bmatrix}J_{r,\varepsilon} & J_{r,\sigma}\\ J_{i,\varepsilon} & J_{i,\sigma}\end{bmatrix}\begin{bmatrix}\Delta\varepsilon_r\\ \Delta\varepsilon_i\end{bmatrix} \quad (1)$$

In the above equation, ΔC_r and ΔC_i represent the real and imaginary part of the complex capacitance measurement respectively. $\Delta\varepsilon_r$ and $\Delta\varepsilon_i$ are the real and imaginary part of the complex admittance respectively. J denotes the Jacobian matrix. For simplicity, Eq. (1) can also be expressed by

$$C = JG \quad (2)$$

where $G = \begin{bmatrix}\Delta\varepsilon_r\\ \Delta\varepsilon_i\end{bmatrix} \in \mathbb{R}^{n\times 1}$, $J = \begin{bmatrix}J_{r,\varepsilon} & J_{r,\sigma}\\ J_{i,\varepsilon} & J_{i,\sigma}\end{bmatrix} \in \mathbb{R}^{m\times n}$, and $C = \begin{bmatrix}\Delta C_r\\ \Delta C_i\end{bmatrix} \in \mathbb{R}^{m\times 1}$.

Then MMV based image reconstruction is proposed to encode the structural features and frequency correlations of the images under different frequencies. The resulting optimisation problem is described by

$$\begin{cases}\min\limits_{Q} \ \|Q\|_{\omega,2,1} := \sum_{i=1}^{n}\omega_i\left\|G^i\right\|_2\\ s.t.\ \ JQ = K\end{cases} \quad (3)$$

where $Q = [G_1, G_2, \ldots, G_q] \in \mathbb{R}^{n\times q}$ is a collection solutions under q frequencies. $K = [C_1, C_2, \ldots, C_q] \in \mathbb{R}^{m\times q}$ is the collection of q multi-frequency measurements. ω is weighting factors.

The ADMM method [3] is applied to solve the image reconstruction problem described by Eq. (3).

3 Results

A single object (non-conductive) imaging experiments were conducted. A typical 8-electrode ECT sensor was used and the background substance is saline of varying conductivity, e.g. 0.2 S·m^{-1} and 0.5 S·m^{-1}. Impedance analyser were used to obtain complex-valued capacitance measurements, which were performed within a frequency range of 2.1MHz to 2.4MHz. The simultaneous image reconstruction results are shown in Figure 1.

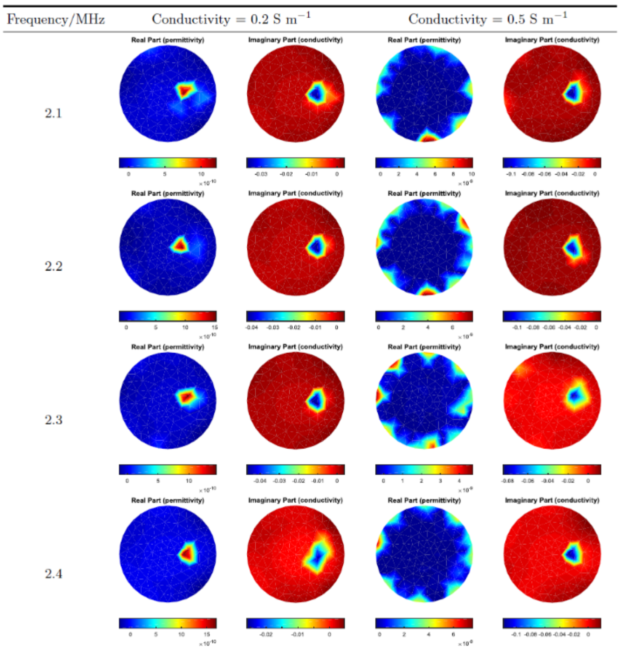

Figure 1: Permittivity and conductivity reconstruction results.

4 Conclusions

The results show that multi-frequency permittivity and conductivity can be reconstructed simultaneously and in high quality based on complex-valued measurement data using ECT sensor and the proposed MMV method. The method is promising for non-invasive biomedical imaging.

References

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