Preliminary Study on the Feasibility of Reconstructing Anatomically Complex Numerical Brain Phantoms with Limited Prior Information

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Background

Driving force:
Non-ionising, low cost, portable, alternative way instead of CT, MRI.

Principle:
Differences between the dielectric properties of tissues.

Potential applications:
Brain/Breast Imaging.

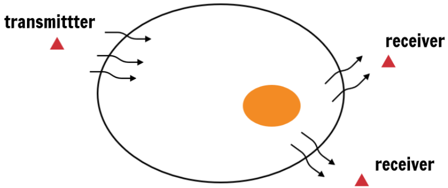
Frequency range:
0.5 to 3 GHz.

MWI system:

- Data acquisition system.
- Imaging algorithms.

Imaging algorithms: CSI, GN, DBIM

- Forward solver: FDTD, FEM, MoM.
- Inverse solver: CGLS, FISTA, TwIST.



Challenges:
Hard to obtain prior information of the brain.

Objectives:
Investigate how the prior information affect the reconstructions and how to improve the reconstructions with limited information.

DBIM with FISTA

DBIM for the inverse scattering problem,

$$E_s(\mathbf{r_n}, \mathbf{r_m}) = \delta_\varepsilon(\mathbf{r})\omega^2\mu \int_V G_b(\mathbf{r_n}, \mathbf{r})E_b(\mathbf{r}, \mathbf{r_m})d\mathbf{r}$$

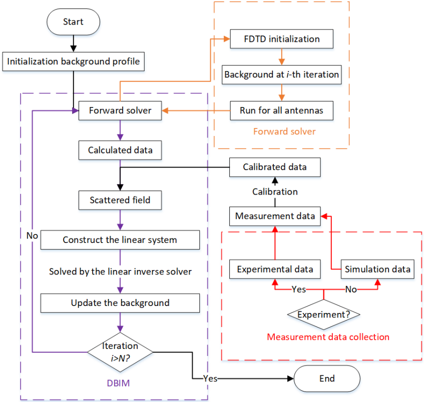
Resulting $b = Ax$, solved by FISTA:

$$x_k = p_L(y_k), y_{k+1} = x_k + \frac{t_k - 1}{t_{k+1}}(x_k - x_{k-1})$$

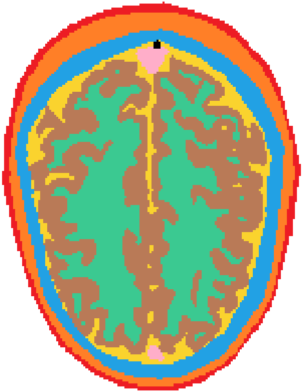
where $t_{k+1} = \frac{1+\sqrt{1+4t_k^2}}{2}$ and p_L is the thresholding operator.

To simulate the frequency-dependent materials in FDTD, Debye model is used,

$$\varepsilon_r(\omega) = \varepsilon_\infty + \frac{\Delta\varepsilon}{1 + j\omega\tau} + \frac{\sigma_s}{j\omega\varepsilon_0}$$



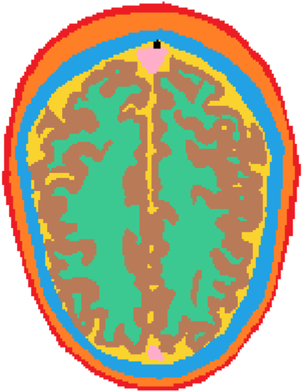
Zubal Head Phantom



A slice has been chosen from the Zubal head phantom derived from MRI-based images by Yale University: http://noodle.med.yale.edu/zubal. Original size of the Zubal head phantom: 256×256×128 with each voxel size of 1.4 mm × 1.4 mm × 1.1 mm. Converted 2D slice resolution used in FDTD: 2 mm × 2 mm. The Debye parameters used are as follows.

Tissue(and color)	ε_∞	$\Delta\varepsilon$	σ_s
skin(red)	37.65	11.36	0.6241
fat(orange)	8.609	2.922	0.07526
bone(blue)	8.483	4.381	0.08252
white matter(green)	35.89	6.729	0.4476
gray matter(brown)	40.03	14.47	0.7158
blood(black)	44.67	18.02	1.322
CSF(yellow)	66.08	4.606	2.338
dura(pink)	39.89	6	0.8537

Zubal Head Phantom



The model is immersed in a homogeneous background material: glycerol 90% water 10% mixture.

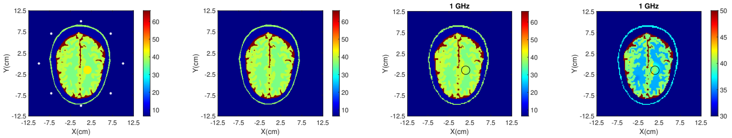
To investigate, some materials are removed and targets are included in the different kinds of models.

8 (when the only unknown is the target) or 16 antennas are used.

The images (ε_∞) of the FDTD model in the next pages are in the order as follows, (a) the true model (b) the information we know (c) reconstructions (d) reconstructions with changed color bar.

Zubal Head Phantom

FDTD reconstruction

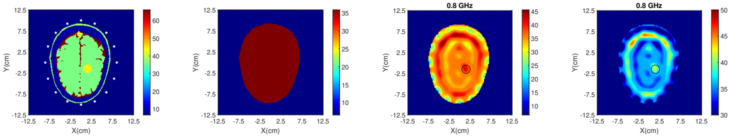


(a) original (b) initial guess (c) reconstruction (d) reconstruction

When the only unknown is the target (blood) even when we have a very complicated model, it is not hard to be reconstructed.

Zubal Head Phantom

FDTD reconstruction

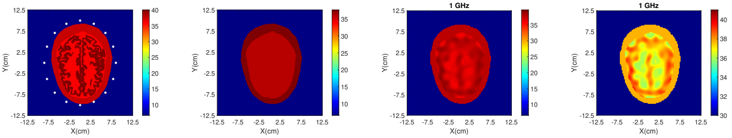


(a) original (b) initial guess (c) reconstruction (d) reconstruction

When the unknown increases (only the boundary of the head with white matter as background is known), it becomes more difficult to reconstruct the region so 16 antennas are used to improve the resolution. We also remove the gray matter layer, the target is clearly detected and the boundary between different layers has also been reconstructed.

Zubal Head Phantom

FDTD reconstruction

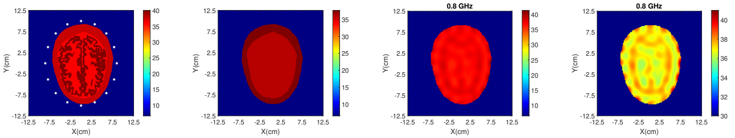


(a) original (b) initial guess (c) reconstruction (d) reconstruction

To reconstruct the big area with gray matter (three layer model, skin, white matter and gray matter), the results are shown above. The gray matter is reconstructed and the resolution is acceptable.

Zubal Head Phantom

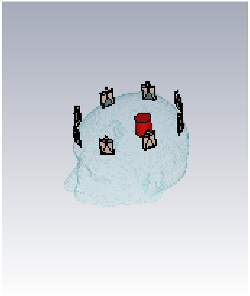
FDTD reconstruction

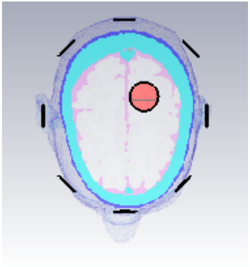


(a) original (b) initial guess (c) reconstruction (d) reconstruction

When assuming only the boundary of the head is known, the reconstructions of the model (same as last slie) are not good as before, as the problem is becoming severely ill-conditioned. The reconstruction is separating the different materials.

Zubal Phantom in CST





Configuration:
The center of the antennas is at the same level where the 2D slice is used.

8 antennas are used.

The blood target is a cylindrical target centered at the same lever as the antenna.

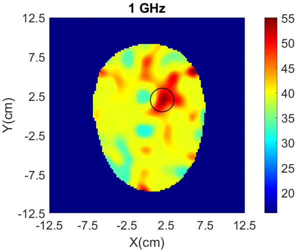
The materials are selected similar as the 2D slice.

Challenges:
As the CST model is 3D model, all the materials are not in normal shapes, thus the influence of the discrepancies increase a lot.

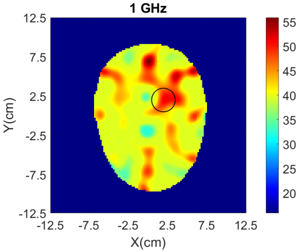
Reconstructions with CST DATA

To do the reconstructions with CST DATA, for each model, two simulations are ran to get the data:
1. The one without the target (for the following, 3D model with only the white matter), called NT.
2. The one with the target, for the following, 3D model with skin, blood target, fat, bone (and CSF or not), called WT.

Figure: Reconstructions of ε_{real} when only the white matter is known



(a) Without CSF in WT



(b) With CSF in WT

Conclusions

- We have investigated the possibility of reconstructing a numerical brain phantom with limited prior information by our recently proposed DBIM-FISTA algorithm.
- With less prior information and with more complex models, the difficulty of reconstructions increases.
- We have further performed some reconstructions with CST data.

Thank you!

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This work was funded by EPSRC and Innovate UK.