Weighted frequency-difference EIT measurement of hemisphere phantom

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Abstract. We have proposed a new frequency difference method using a weighted voltage difference (WFD-EIT) between two frequencies [1, 2]. Previous studies demonstrated its feasibility through numerical experiments and two-dimensional phantom experiments. In this study, we validate the WFD-EIT algorithm on a three-dimensional hemisphere phantom using a multi-frequency EIT system KHU Mark1. We built the hemisphere phantom with 17 stainless-steel electrodes on its inner surface. We filled the phantom with a biological material having a frequency-dependent admittivity such as carrot pieces mixed in saline. Using boundary voltage data from the deformed phantom, we reconstructed weighted frequency difference images on the computational model domain with a hemisphere shape. We discuss comparative reconstruction performance results including time difference (TD), simple frequency difference (FD), and weighted frequency difference (WFD). Animal and human head imaging experiments with the weighted frequency-difference EIT method are under investigation.

1. Introduction

The weighted frequency-difference (WFD) EIT algorithm is promising since it may extract a useful information related to an anomaly in a background with a frequency-dependent admittivity. We expect that it is advantageous to overcome common errors and artefacts in frequency-difference EIT imaging [1, 2]. There always occurs some mismatch between experimental and computational domains. In performing human experiments, boundary movements are caused by motion and breathing. Seo et al. showed that the WFD method is robust against boundary geometry error using numerical simulations [1]. In this work, we investigate how the WFD algorithm deals with a deformation of the boundary shape. We present results of numerical simulations and imaging experiments using a deformed hemisphere as an imaging object.
2. Experimental design and methods

We prepared a hemispherical phantom filled with either saline or carrot pieces suspended in saline. As an anomaly, we used a cylindrical piece of banana and potato. The diameter of each anomaly was 20% of the diameter of the phantom. Images were reconstructed using time-difference (TD), simple frequency-difference (FD) and weighted frequency difference (WFD) methods from simulation data at 1, 5, 10, 50 and 100 kHz. We used a single-step algorithm based on a sensitivity matrix and the truncated singular value decomposition (TSVD). For the weighted frequency-difference method, the reference frequency of $\omega_0/2\pi = 1$ kHz was used to estimate an equivalent homogeneous admittivity. We acquired experimental data from the hemisphere phantom using the KHU Mark1 multi-frequency EIT system operating from 1 kHz to 500 kHz [3].

![Conductivity spectra of saline, mixture of carrot pieces with saline, potato and banana](image)

**Figure 1.** Conductivity spectra of saline, mixture of carrot pieces with saline, potato and banana.

![Computational hemisphere model](image)

**Figure 2.** Computational hemisphere model: (a) xy-view and (b) yz-view.

![Hemisphere phantom filled with carrot pieces in saline and the KHU Mark1 EIT system](image)

**Figure 3.** (a) Hemisphere phantom filled with carrot pieces in saline and the KHU Mark1 EIT system. (b) Same phantom filled with saline and banana anomaly.
2.1 **Direct impedance measurement**
We measured conductivity spectra of 5% saline, mixture of carrot pieces with 0.1% saline, potato, and banana using a BIS system from 1 kHz to 500 kHz. Figure 1 shows their conductivity spectra. Conductivity values of banana increased with frequency and crossed that of saline at around 10 kHz, and conductivity of potato crossed that of carrot pieces in saline at around 100 kHz.

2.2 **Tank preparation**
There were 17 electrodes located on the surface of a hemisphere model $\Omega = \{(x, y, z) \mid x^2 + y^2 + z^2 \leq 9^2, z \leq 0\}$. The eight electrodes per layer were equally spaced around its circumference as shown in figure 2(a). One ground electrode was located on the apex. In numerical simulations, we generated simulated data on an elongated hemisphere in the x-direction as $\Omega_1 = \{(x, y, z) \mid (x/1.1)^2 + (y/0.9)^2 + z^2 \leq 9^2, z \leq 0\}$ with the same electrode configuration as $\Omega$. We reconstructed images in the original hemispherical model $\Omega$ to see effects of modelling error. For the phantom experiments, we also used a deformed phantom $\Omega_1$ to measure the boundary voltage data, then reconstructed images using the hemisphere model $\Omega$. We filled the phantom with either 5% saline or a mixture of carrot pieces (60%) and 0.1% saline (40%). We placed an anomaly of cylindrically-shaped banana or potato at the position of (-5.0, 0) cm in $\Omega_1$.

3. **Results**

3.1. **Numerical simulations**
We could observe that geometrical modelling error affects the appearance of the anomaly in reconstructed images. Compared with the FD method, the WFD method showed better performance with reduced artefact in reconstructed images (Figure 4).

![Figure 4. Reconstructed images by numerical simulations. We reconstructed four images for each case at 5, 10, 50, and 100 kHz. (a) The banana anomaly in the saline background (b) The potato anomaly in the mixture of carrot pieces and saline as the background. The pixel values mean percentile changes of conductivity.](image)

3.2. **Phantom experiments**
Figure 5 shows results of phantom experiments. In the saline background, both FD and WFD methods produced comparable images. However, the location of the anomaly using the FD method was slightly shifted toward the center. The anomaly position in images by using the WFD method was closer to the true position. When the background was the mixture of carrot pieces with saline, the WFD method yielded a visible anomaly conductivity contrast while the FD method failed to locate the anomaly. Images of the TD method distinguished the anomaly well for all cases.
Figure 5. Reconstructed images from phantom experiments. We reconstructed four images at 5, 10, 50, and 100 kHz for each case. (a) The banana anomaly in the saline background. (b) The potato anomaly in the mixture of carrot pieces and saline background. The green vertical line denotes the y-axis at (0, 0).

4. Conclusion

We demonstrated how boundary geometry errors between the imaging object and a model domain affect image reconstructions for three algorithms including the time difference, simple frequency difference and weighted frequency difference. Compared with the simple frequency-difference method, the weighted frequency-difference method yields better images showing its robustness against modelling errors.

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6. References

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