Assessing the feasibility of detecting a Hemorrhagic type stroke using a 16 channel Magnetic Induction System

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Abstract. Magnetic induction tomography (MIT) has been proposed as a possible method for imaging stroke in the human brain. Hemorrhagic stroke is characterized by local blood accumulation in the brain and exhibits a greater change in conductivity with frequency compared to other tissues which is observed in the frequency range of interest [1-10] MHz. In this study, we investigate the feasibility of detecting hemorrhagic stroke using absolute and frequency difference imaging. For this purpose, a model of the head originally obtained from MRI and X-ray data was used, to which a large stroke (50 ml) was added. In addition, a model of a 16 channel circular array MIT system was employed. The received coil induced voltages were computed using a custom eddy current solver, based on the finite difference method. For absolute imaging, the induced voltages at the receiver coils were calculated from various coil combinations at 10 MHz frequency together with anticipated systematic errors and biases (orientation and displacement of the coils, movement of the head). The induced voltage noise due to these systematic inaccuracies was compared with the voltage change due to the stroke. In order to decrease the impact of this noise, frequency difference was also considered, whereby measurements were performed at another frequency (1MHz) and subtracted. Comparison results are presented and a realistic picture is delivered with to regard the required mechanical stability and electronics accuracy for this particular medical application.

1. Introduction

Magnetic Induction Tomography (MIT) is a non-intrusive modality that has been proposed as a possible method for imaging changes in electrical properties of biological tissues. The stroke is a life threatening pathological condition involving an accumulation of fluid in the brain. When the condition is due to blood leakage, the stroke is characterized as a hemorrhage. This blood accumulation causes the local conductivity in the region to change; hence MIT can be suitable for detecting or monitoring the condition. Recently, considerable research was devoted to investigate this MIT application [1]. In this paper we investigate the possibility of detecting a hemorrhage type stroke by examining the signal due to the stroke against that of systematic errors that can happen in a real MIT system.

2. Results and discussion

Figure 1a) and b) shows the simulation arrangement which includes a head model and an MIT system. This latter consists of a cylindrical shield with radius of 175 mm, height of 250 mm, and a circular coil array which consists of 16 excitation coils and 16 receiver coils (diameter 50 mm) modeled as filamentary and arranged in two concentric circles at radii of 142.5 mm and 132.5 mm surrounding the target. Unit current is passed through the excitation coil and induced voltages are...
measured through the inner receiver coils. A model of the head (Figure 1a) consisting of 7 biological tissues (Scalp, Skull, CSF, gray matter, white matter, spinal/optic nerves, and Eye balls) is placed in the scanning region so as the stroke line up with the sensor plane. The electrical conductivities for the corresponding tissues were obtained from [2]. The voltages induced on the receiver coils are computed using a custom eddy current software developed by our group at the University of Manchester. The package employs a pre-computed primary field \( A_0 \) by an FE package (e.g. COMSOL) and solves the MIT forward problem using the impedance method [3].

In a first analysis, one transmitter is excited and the differences in the voltage induced because of the presence of the head between the transmitter being in the correct orientation (solution 1) and the transmitter being rotated by one and two degrees (solution 2) are calculated for every receiver channel (equation (1)). The values are normalized to the rms of the induced voltages produced by the noise free case and plotted against channel number (Figure 2a). Receiver coil numbers are in order; number R1 and R15 are adjacent to transmitter T0, and R8 is the opposite receiver.

\[
d\bar{V} = \frac{\Delta V_{\text{solution 1}} - \Delta V_{\text{solution 2}}}{\text{RMS}(\Delta V_{\text{solution 2}})}
\]

(1)

Figure 2. Relative voltage errors caused by the coil rotation/displacement
From the graph (Figure 2a), we can see that the worst effected coils are the coils near the transmitter where the opposite coil has nearly zero error. On the same graph, the voltages induced by the background magnetic field are also plotted. The relative changes in the background measurements are smaller than the error in the secondary induced voltages except for the adjacent coils. The lines do not follow the same trend; hence it is difficult to use the background to compensate for the error on the secondary field.

On the other hand, figure 2b presents the results of the simulations for displacing the transmitter coil by 1 and 2mm along its axis towards the centre of the object space. As can be seen, similar observations made for the mis-orientation of the coil earlier, remain valid for when the transmitter coil is displaced. In a second simulation, the effect of the displacement of the head to measurements differences is quantified. The head is moved by 2 mm toward $R_4$ and the relative voltage differences are plotted on the graph below (Figure 3). In this case, we can see that MIT is not as sensitive to the movement of the head as to the movement of the coils. The changes of the signal caused by the 50 ml stroke (inclusion) are also mapped in the figure for comparison. The relative signal from the stroke is in the same order of magnitude compared to the relative voltage errors caused by the movements of the coil and the head. This means that for a system that is built with these tolerances it will be very difficult to reconstruct the stroke.

Recently frequency difference imaging has been suggested as attractive for imaging the stroke since biological tissues exhibit conductivity changes with frequency. Workers in the field of MIT reported this procedure whereby dual frequency measurements are used can reduce systematic errors investigated above [4]. In order to test if frequency difference can reduce the error caused by coil positioning, the following computational experiment was conducted. The induced voltages due to the presence of the head were computed at frequencies of 1 and 10 MHz for the case when the transmitter was in the correct position (solution 1) and displaced (i.e. rotated/moved - solution 2). The voltage differences were calculated in a similar fashion to the absolute case and have been normalized to the rms value of the frequency difference measurements for the correct position according to the equation given below:

$$dV = \frac{(\Delta V_{f_1} - (f_1/f_{12})^2 \Delta V_{f_{12}})_{\text{solution1}} - (\Delta V_{f_1} - (f_1/f_{12})^2 \Delta V_{f_{12}})_{\text{solution2}}}{\text{RMS}((\Delta V_{f_1} - (f_1/f_{12})^2 \Delta V_{f_{12}})_{\text{solution}})}$$ (2)
In figure 4a), we can observe that there is no improvement on the relative error caused by the movement of the coil.

![Figure 4. Comparison of errors between absolute and frequency difference measurements](image)

The error cancelation when frequency difference measurements are used is also tested for head displacement (Figure 4b). Interestingly, the absolute and frequency difference relative error show similar pattern, which infers that there is no advantage of using frequency difference for head displacement error cancelation.

3. Conclusion
Nowadays the acquisition electronics used for MIT systems have been developed to a degree that different types of errors are more obvious in real MIT arrays. The positioning of the coils in a MIT system is very critical as well as the accurate knowledge of the target location and the shape. The tolerances of the coil array should be less than one tenth of a millimeter in order for the accuracy of the measurements to be the same order to the noise generated by the electronics.

4. References

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