Cryosurgical Monitoring Using Electromagnetic Measurements- A feasibility Study for Magnetic Induction Tomography

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Abstract- Magnetic Induction Tomography (MIT) is an emerging type of tomography technique that is sensitive to passive electromagnetic properties. Because the non-invasive and contactless nature of MIT, it has advantages over traditional contact electrodes based tomography techniques for biomedical applications. This paper presents a feasibility study of applying MIT for cryosurgical monitoring. This is important because the cryosurgical process requires real time monitoring to acquire the knowledge of freezing extent in order to maximise the effectiveness. A Bath medical MIT system was adapted for this application. A mathematical model based on this system was developed to solve the eddy current problem using edge finite element method (FEM). The forward model was used to calculate the induced voltage for a pre-defined conductivity distribution. This paper mainly studies the signal perturbations caused by characteristics of the inclusion during the freezing process, in terms of frozen location, frozen volume and the conductivity of the frozen region.

I. Introduction

Magnetic Induction Tomography (MIT) is a type of electrical tomography technique that can image the spatial distribution of passive electromagnetic properties (conductivity, permeability and permittivity) in the region of interest (ROI); although conductivity is usually the focus [1]. The application of MIT envisaged in this paper, as a motivation, is monitoring of cryosurgery. Cryosurgery is a minimally invasive way of destroying the undesired tissues by freezing them down to between -20 to -80 degree [4]. Feasibility of Electrical Impedance Tomography (EIT) for Cryosurgery monitoring has been studied in [4]. MIT could potentially provide a suitable solution for this monitoring. The fundamental principles of MIT are as follows: by passing a sinusoidal signal through an excitation coil, it can produce a primary magnetic field (B) that induces the eddy current in ROI. This eddy current can then generate a secondary magnetic field (ΔB) that can be detected by sensing coils. Since the properties of the secondary magnetic field depend on the material's properties, analysing this detected secondary field reveals information of the material. Compare with conductivity features for industrial MIT system ($\sigma > 10^6$ S/m), the conductivity contrast for biomedical MIT system is usually very low ($\sigma <$ 3 S/m), the signal perturbations caused by biological samples is generally less than 1%, which implies the perturbation is mainly dominated by the phase shifts, i.e. Im(ΔB/B), which contains the required information for image reconstruction [1, 2]. In this study, the changes in induced voltage were simulated by using forward model for cryosurgery monitoring [4, 6].

I. Methods

A. Measurement system

Our system consists of (i) a coil array of equally spaced 16 sensors, (ii) a National Instrument (NI) based data acquisition system and (iii) a host computer. There are different types of coil can be used for MIT systems; an air-core coil was chosen for our system because of its low cost, design simplicity and linearity performance. As shown in Figure1, 16 hand-wound coil sensors were equally spaced to form a radius of 12cm imaging region. Each coil has 6 turns, the side length is 1cm, and the radius of the coil is 2cm. It is worth noticing that only 8 coils are engaged for transmitting signals, and the other 8 coils are dedicated for receiving signals; which indicates the total number of independent measurement is 64. A grounded aluminium cylinder was constructed to prevent external electric field perturbation. Because of the nature of low contrast conductivity of biomedical tissues, the system requires accurate measurement devices to improve the sensitivity. A NI 2953 was employed to realise the multi-channel switching process. A NI 5781 was connected to collect data, combine data and display data to suit the need for real time monitoring. In order to improve the system efficiency, a NI 7951 FlexRIO board was employed to speed up the data acquisition process. The image reconstruction module extracts 64 independent measurements to perform the reconstruction algorithm, displays and updates the images. Detailed description of system designing and further evaluation of driving signal level, phase noise and phase drift have been studied in [3].

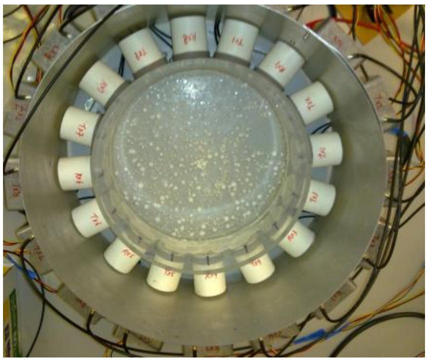

Figure1. The coil array of Bath medical MIT system

B. Mathematical Model

In this study, a mathematical model was established which utilises edge FEM to analysis the numerical problem of eddy current. The aim of solving forward problem is to calculate the induced voltage for a pre-defined conductivity distribution, which can be used to compare with the real measurements collected from the system for validation and image reconstruction. The conductivity of shielding (σ=3.5X10^7S/m) is very high compare to the conductivity of biomedical tissues, consequently, the calculation of forward model will be dominated by the high conductivity distribution, therefore the shielding was excluded from this simulation. As we intend to reconstruct images using 2D system; a cylindrical geometry was adopted for simulation as shown in Figure 2; where the large cylinder represents conductive background with uniformed conductivity of 1S/m and the small cylinder stands for frozen region with low conductivity of 10^{-5} S/m. This way, the variation along z-axial dimension can be neglected.

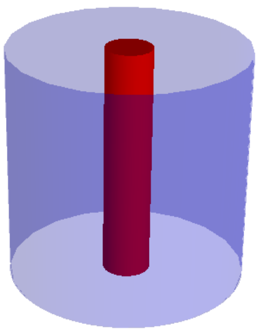

Figure 2 Cylindrical geometry used for mesh model (only conductive region is shown)

In this paper, a reduced magnetic vector potential was adopted to avoid modelling the structure of the coils using edge FEM [3, 5]. The magnetic potential is constituted of two parts $A = A_s + A_r$; where A_S represents the magnetic vector potential as result of current source (excitation) and A_r represents the secondary magnetic vector potential. In the A, A formulation we have:

$$\nabla \times (\frac{1}{\mu} \nabla \times A) + j\omega\sigma A = J_s$$

where current density J_s can be prescribed by magnetic vector potential from Biot-Savart Law, μ is permeability, σ is conductivity and ω is angular frequency.

III. Results

The cross section of imaging region was shown in Figure 3. Assuming the conductivity in background region Ω_2 is 1 S/m, the radius (R) of background (Ω_2) is 12cm. The centre of the mesh geometry locates at (0, 0, 0) in cartesian coordinated system. The radius (r) of inclusion (Ω_1) is 2cm, locating at the centre of the imaging region at initial state. All measurements have been normalised against the background measurement. In all cases, an adjacent and an opposite measurements were simulated in order to show the changes in induced voltage. The locations of adjacent and opposite coils are shown in Figure 3. Figure 4 shows how the conductivity of inclusion affects the induced voltage; whilst the frozen region has very low conductivity. Figure 5 shows changing in induced voltage against the volume of the frozen region. Figure 6 shows changing in induced voltage against the location of inclusion along x-axis; where the inclusion is moving from centre to edge of the ROI.

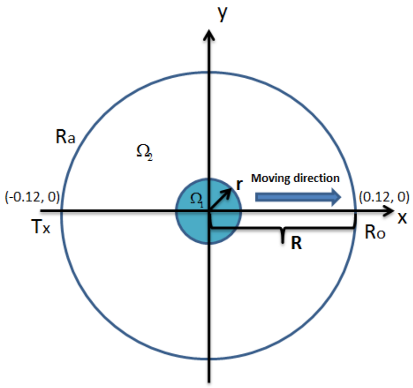

Figure 3 Cross section of ROI (Tx shows a transmitting coil, Ra and Ro show the locations of adjacent and opposite measuring coil to Tx)

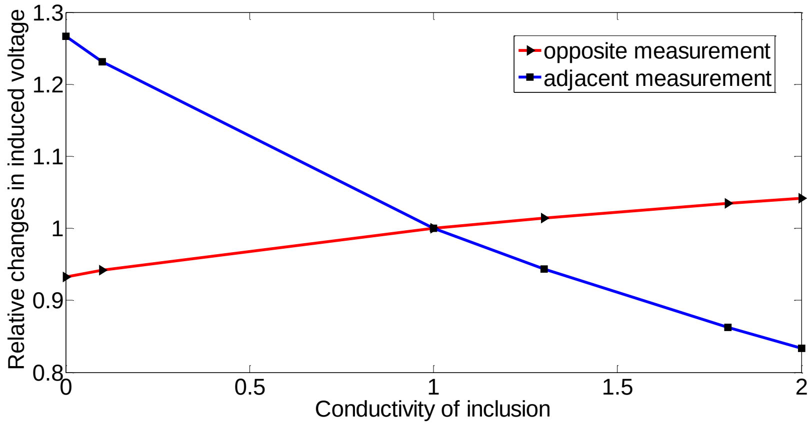

Figure 4 Relative changes in induced voltage vs Changes in conductivity of inclusion

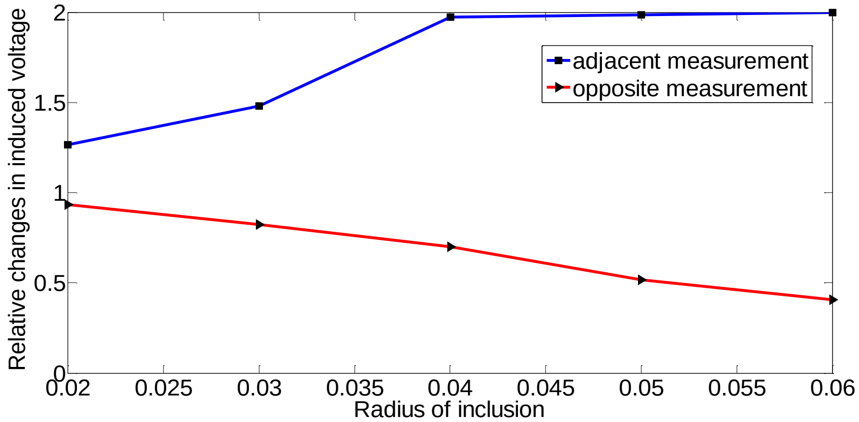

Figure 5 Relative changes in induced voltage vs Volume of inclusion

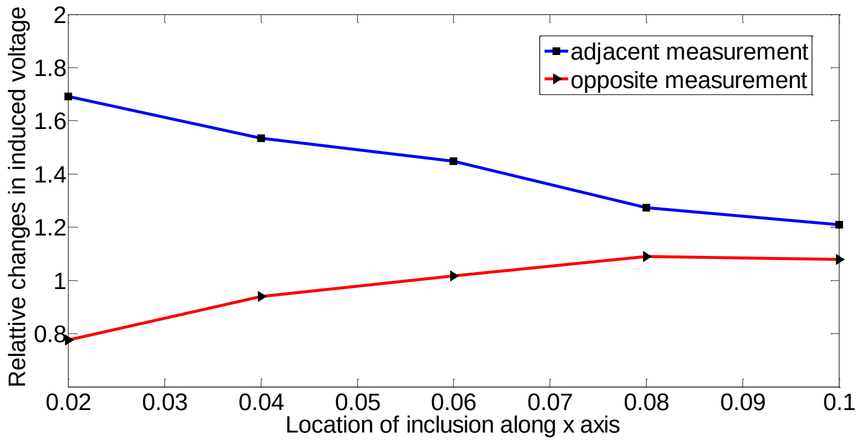

Figure 6 Relative changes in induced voltage vs Location of inclusion along x-axis

IV. Conclusion

The simulated changes in induced voltage have indicated the signal perturbations are measurable by MIT system. Further experimental investigations are being carried out to validate the forward model. For cryosurgical monitoring, we intend to use a localised image reconstruction algorithm [6]. This will make the image reconstruction more accurate as the location of the treatment area is known using initial diagnostic methods.

Reference

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