Application of the Focused Impedance Method (FIM) to Determine the Volume of an Object Within a Volume Conductor

M. Abdul Kadir[1], Syed Parvez Ahmed[2], Golam Dastegir Al Quaderi[3], Rubina Rahman[2], K. Siddique-e Rabbani[1]

[1]Department of Biomedical Physics & Technology, University of Dhaka, Dhaka, Bangladesh
[2]Department of Physics, Jahangirnagar University, Savar, Dhaka, Bangladesh
[3]Department of Physics, University of Dhaka, Dhaka, Bangladesh

Abstract

Introduction: Focused Impedance Method (FIM), an innovation of our extended group at the University of Dhaka [1] has localised sensitivity distribution [2], and hence can measure the change in transfer impedance of a specified target zone within a volume conductor minimizing the contribution from its neighbours. The present work was taken up to determine the volume of an object embedded in a volume conductor with different impedance properties. A new method based on varied electrode separations (ES) of a few concentric 4-electrode FIM configurations is described.

Methods: A cubic tank of edge 30cm filled with saline was modelled as a volume conductor in COMSOL Multiphysics® with small cylindrical electrodes placed on one of the sides, centrally. A spherical object of radius (r) of conductivity different from that of the saline was assumed to be placed at the center of the four electrode configurations at a depth (d) from the electrode plane (figure 1). 3D sensitivity distribution for FIM measurements of this COMSOL model was evaluated using standard sensitivity equation [3] involving current density products. The FIM measurements were taken by injecting an alternating current of constant amplitude sequentially through electrode pairs (A,B) and (A,C) using the Electric Currents (ec) interface of the AC/DC Module and measuring the resulting voltage difference across the corresponding Boundary Probes (C,D) and (B,D) respectively. The studies were performed in the frequency domain at 5 kHz. Focused impedance (FZ) was then derived from the sum of two tetra-polar transfer impedance values calculated from the ratio of the injected current to the measured voltage.

Results: Figure 2 shows the enhanced sensitivity distribution at the central zone of the 4-electrode FIM configuration. It was found that the Focused Impedance (FZ) decreased with increased ES (figure 3) with the slope $S=\Delta FZ/(ES2-ES1)$ of FZ vs ES curve being linearly proportional to object volume (V) for a constant d (figure 4). Again for a constant V, the slope of S vs V curve is inversely proportional to d. Assuming $ES1>d>0$ and $ES1>2r>0$, it was shown that V can be obtained from the equation $S=[(K/d)+B]*V+C$ where K, B and C are constants that

depend on the saline and the object conductivities, dimensions of the container and electrode properties; in this case, estimated from the COMSOL simulation. In a practical phantom, made identical to that used in COMSOL model, FZs due to an object of arbitrary volume placed at a known depth were measured for two different ES wherefrom the object volume was calculated using the above equation. Comparison of the calculated volume to the actual volume of the object inserted showed that the proposed method can give the volume with error less than 5%.

Conclusion: Although the study was performed only for spherical objects, the proposed noninvasive and non-ionizing FIM technique of volume determination has the potential of estimating volume of an organ within the human body, for instance, estimating the food content in the stomach. The method may also be used to estimate volume of subsurface mines.

Reference

1. K S Rabbani and M A S Karal, A new four electrode focused impedance measurement (FIM) system for physiological study, Ann. Biomed. Eng. 36, 1072–7(2008)
2. N Islam et al, The sensitivity of focused electrical impedance measurements, Physiol. Meas. 31, S97–S109 (2010)
3. S Grimnes , Ø G Martinsen, Bioimpedance and bioelectricity basics, 2nd ed. Academic press; 2008

Figures used in the abstract

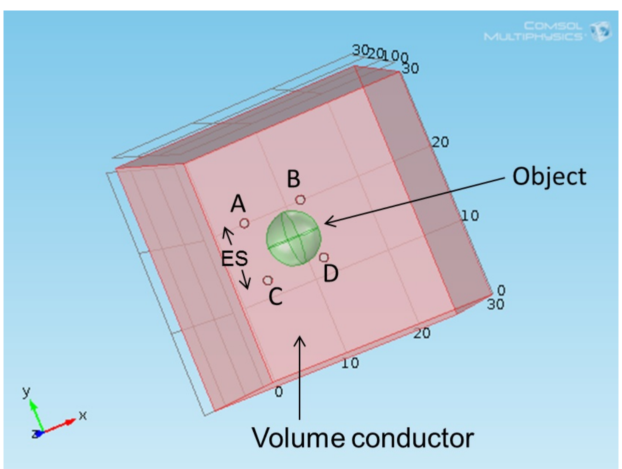

Figure 1: COMSOL model used in the volume determination study.

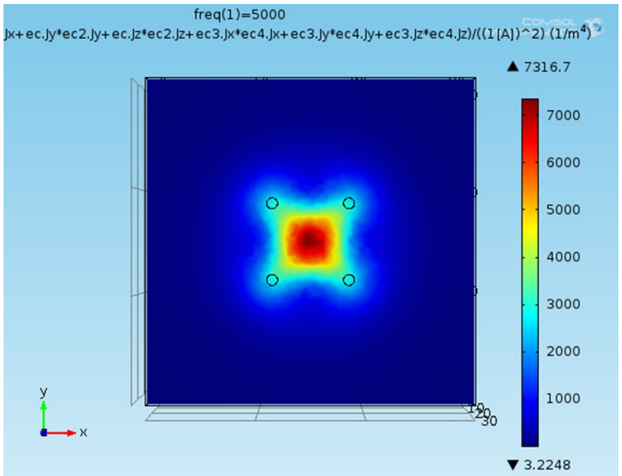

Figure 2: Sensitivity distribution of FIM at a plane at 3cm depth from the electrode plane showing enhanced sensitivity at the central zone.

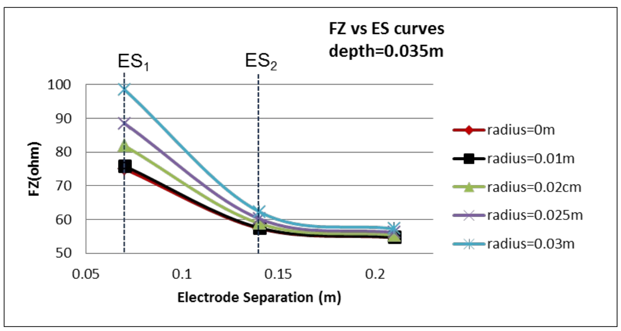

Figure 3: Change in Focused Impedance with increasing electrode separation for objects of different radius (r=0 means no object).

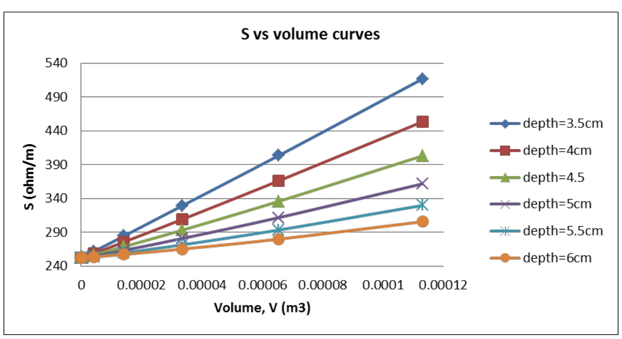

Figure 4: Linearity of S with object volume at different depth.