3D sensitivity of 6-electrode Focused Impedance Method (FIM)

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Abstract: The present work was taken up to have an understanding of the depth sensitivity of the 6 electrode FIM developed by our laboratory earlier, so that it may be applied judiciously for the measurement of organs in 3D, with electrodes on the skin surface. For a fixed electrode geometry sensitivity is expected to depend on the depth, size and conductivity of the target object. With current electrodes 18 cm apart and potential electrodes 5 cm apart, depth sensitivity of spherical conductors, insulators and of pieces of potato of different diameters were measured. The sensitivity dropped sharply with depth gradually leveling off to background, and objects could be sensed down to a depth of about twice their diameters. The sensitivity at a certain depth increases almost linearly with volume for objects with the same conductivity. Thus these results increase confidence in the use of FIM for studying organs at depths of the body.

1. Introduction
The 6 electrode Focused Impedance Method (FIM) developed by Dhaka University [1][2] is mainly targeted at probing single objects in 3D inside the human body by placing electrodes on the skin surface. FIM consists of essentially the sum of two orthogonal Tetrapolar Impedance Measurement (TPIM) systems placed symmetrically around a central zone. A conventional TPIM system has four electrodes in a row; the outer pair (to be called current electrodes) drives a current through the test medium while the central pair (to be called potential electrodes) is used to make a potential measurement. FIM gives an enhanced sensitivity within the zone surrounded by the potential electrodes. Two conventional TPIM configurations for FIM would require 8 electrodes, however, by placing 2 potential electrodes diagonally in the central region the requirement of the number of electrodes have been reduced to 6, since these two potential electrodes can work with both the orthogonal measurements. Sensitivity mapping in 2D saline phantoms with cylindrical objects of different conductivity placed at different points has shown success in the focusing effect.

As mentioned before, the main applications envisaged with FIM will try to measure the impedance of single organs at a depth using FIM electrodes on the skin surface, which essentially is a measurement in the 3rd dimension. Besides, FIM would be used to look for changed impedances in an organ, thus eliminating the effect of surrounding tissues and organs whose impedances do not change. This change in impedance may be either due to physiological changes with time, or due to change in tissue impedance with measuring frequency of the instrument. FIM has been applied successfully for the measurement of stomach emptying, the results agreeing very well to that obtained using region of interest analysis of EIT images [2]. It also shows promise in the measurement of ventilation of lungs.
Bladder emptying, tissue temperature monitoring during therapy procedures in cancer, and diagnosis of epithelial cancers, like cervical and oral cancer, may be some other areas where FIM may find useful application.

Numerical analysis performed on FIM at Warwick University, UK, using Geselowitz’s lead field method has confirmed the focusing effect of 6-electrode FIM [4] in a medium with uniform conductivity. A maximum in the average sensitivity of a plane was observed at \(1/3\) of the drive-receive electrode spacing. Negative sensitivity, usual with all tetrapolar impedance systems, appeared down to \(1/2\) of the drive-receive electrode spacing. No attempts were made to study the effect of a differential measurement with and without an object with a changed conductivity within the focused zone. However, it may be anticipated that all other sensitivity values, including the negative ones, will cancel out except that at the object if it is placed within the focused zone.

Since most applications would involve placing the FIM electrode on the skin surface targeting at objects at a depth, a detailed understanding of the 3D sensitivity is necessary to utilize the method with confidence. As can be envisaged, the measured impedance would depend on the conductivity, depth and volume of the target object provided the geometry of the FIM system and all other parameters are kept unchanged. Therefore effects of changing these parameters need to be understood independently. The present work was taken up to estimate the 3D sensitivity of an object in such a differential measurement placed centrally in the focused zone, through measurements in a phantom with fixed FIM geometry.

2. Methods and measurements
FIM measurements were carried out at 10kHz using a saline filled 3D phantom, made of transparent acrylic, of dimension 50cm x 50cm x 50cm (related to actual depth of water in the tank) as schematically depicted in figure 1. Electrodes (shown by black dots) were fixed on one side while a spherical object (shown as a dark circle) under measurement was hung from the top using a thin thread, guided by calibrated scales. The spacing of the current drive electrodes in each pair was 18cm, while the spacing between the diagonal potential measuring electrodes was 5 cm. The latter corresponds to a focused zone with the dimension of about 3.5cm square at the surface. In 3D the focused zone is expected to increase slightly because of the curvature of equipotential surfaces. Care was taken so that the object is placed centrally within the focused zone while hanging it at different depths from the electrode plane. The position of the spherical object was referred to by the position of its centre. Since the current amplitude is constant, measured potential is proportional to impedance, and this is presented as a value of impedance, in arbitrary units. Insulating and conducting spheres of various diameters were used for the measurements. Potatoes cut to make spheres of various diameters were also used to get objects with intermediate conductivity.

3. Results
The potentials obtained in a constant current measurement system are proportional to the impedance, and hence the measured potential values are directly shown as impedance in arbitrary units in the figures presented in this section. These are shown in the same scale for all the objects, and therefore the values may be compared from the magnitudes shown. Figure 2 shows the measured impedance for insulating spheres while the impedance variation with volume at a certain depth (5 cm) is shown in figure 3.
It can be seen from figure 2 that the measured impedance falls sharply with depth, till it levels off with the background value. Besides, the impedance values are greater for larger objects, and correspondingly, the depth of sensitivity also increases with object size. Figure 3 shows that at a certain depth, the impedance increases almost linearly with volume. Variation of impedance with depth for different spheres of a conducting object and potato are shown in figures 4 and 5 respectively. For the conductor the curves bend in the opposite direction, showing reduced impedance as expected. Potato has greater impedance than the saline used in the phantom, therefore it has impedance change in the positive direction. Distinction from the background (at about 1 to 2 % level) could be made at depths of more than twice the diameter of the objects. As mentioned before, the geometry of the FIM electrodes were the same for all the above measurements.

4. Discussions

A visualization of the depth sensitivity may be obtained from figure 6 showing a cross section in the 3rd dimension with electrodes fixed in the topmost surface as indicated by the small rectangles. The middle two are the potential electrodes and the equipotential surfaces going through these two electrodes define the limits of the sensitive zone, shown gradually shaded, darker shade representing higher sensitivity, schematically. Two factors contribute to the sensitivity of measurement at the top electrodes. Firstly the current density at the position of the object, and secondly, the perturbation in
equipotentials created by the object at the potential measuring electrodes. Because of this, the object O1 will have higher sensitivity than O2. This may also be viewed from another angle. Because of curvature of equipotential surfaces in 3D, as indicated in the figure, the size of the focused zone is expected to increase with depth. Therefore, an object of a specific size takes up less and less fraction of the focused zone as it is taken to greater depths, with consequent decrease in sensitivity. Of course sensitivity would also depend on the spacing of the current and potential electrodes and the conductivity of the object, which need to be studied as well.

The present work gives a confidence in the use of the essentially 2D FIM system for measurements of objects in 3D and justifies the use of the system for studying organs at depths from the skin surface. Having an assessment of the sensitive depths for organs of different sizes, FIM may be applied judiciously for different practical implementations. As mentioned before, FIM is to be applied for measuring changes in impedance of a particular organ, either under different physiological conditions, or with different frequencies of measurement. If neighbouring organs do not have impedance changes under these situations then it is only the target organ that would be ‘visible’ to FIM and its relative changes in impedance can be reliably measured. Of course one has to take note that measuring absolute values of impedance would be difficult, if not impossible. However, relative measurement of impedance change can give a host of diagnostic information which would be easy to measure. Thus the present work paves the way to a better understanding of the FIM for clinical applications.

5. References

[1] Rabbani KS, Sarker M, Akond MHR and Akter T 1998 *Proceedings, X Int. Conf. Elect. Bioimpedance, Barcelona, Spain*, 31-34

[2] Rabbani KS, Sarker M, Akond MHR and Akter T 1999 “Electrical Bioimpedance methods”, *Annals of the New York Academy of Sciences*, 873 408 – 200

[3] Kadir MA, Baig TN and Rabbani KS 2009 *Proceedings (on-line), 10th International Conference on Biomedical Applications of Electrical Impedance Tomography (EIT 2009), Manchester, UK*, http://www.maths.manchester.ac.uk/eit2009/abstracts/kadir.pdf

[4] Islam N, Rabbani KS and Wilson A 2009 *Proceedings, 10th Int Con, Biomed Appl of El Imp Tomography (EIT2009) and Workshop on Electromagnetic Inverse Problems*, http://www.maths.manchester.ac.uk/eit2009/abstracts/islam.pdf