Sensitivity of four-electrode focused impedance method (FIM) for objects with different conductivity

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Abstract

This work presents the results of an empirical study of the sensitivity of a four-electrode FIM technique developed by us earlier, for objects of different conductivity. FIM has potential for the characterization of biological tissue in physiological study and diagnosis. Experimental measurements were performed on a 2D phantom made up of saline with a focused square zone at the centre. Three cylindrical objects of different conductivities (an insulator, a conductor, and a piece of potato offering an intermediate conductivity) were used for the sensitivity measurements. Adjacent square zones had sensitivities of about 22% of that at the center for the insulator, about 13% for the conductor and about 10% for potato, showing a better focusing in the last case. The outer locations had negligible sensitivities. Inverse (negative) sensitivity, which is unavoidable in tetrapolar impedance measurements, was small and negligible in all the cases. Degree of perturbation of equipotential lines has been suggested to be the cause of the above differences in focusing, less perturbation giving rise to better focusing, which would apply for most biological objects to be studied using FIM.

Keywords: Focused Impedance Measurement, FIM, Electrical Impedance, Bioimpedance, Impedance sensitivity

Short title: Conductivity dependent sensitivity in 4-electode FIM

Introduction

There is a potential for the use of electrical impedance techniques for physiological investigation and diagnosis since electrical properties of body-tissues vary widely between different organs, and also between health and disorder[1,2,3]. The Biomedical physics Laboratory of the University of Dhaka conceived of and developed a new methodology, termed as focused Impedance measurement (FIM), which can localize a zone of interest in a volume conductor with simple electronic instrumentation. Two variations of FIM were developed. In one, six electrodes are needed to obtain impedances in two orthogonal directions, the sum of which has a predominant contribution from the central region, and hence is said to be focused[4,5]. The other method uses four electrodes to obtain the sum of impedances in two orthogonal directions [6,7] and has slightly reduced focusing compared to the former, but has the advantage of reduced number of electrodes. It can also be used in the transverse plane, while the former can be used from one side only, typically in the frontal plane.

In the four electrode technique, electrodes are placed on the corners of a square shaped focused region as described later. This is essentially a 2D technique, but since electrical current spreads in all possible directions, 3D sensitivity into the body may be utilized to get information on large organs like stomach, lungs, bladder or heart, or on tissues close to the skin using surface electrodes. Of course placing the electrodes in the transverse plane, deeper structures may be studied. The electrode configuration is the same as used by Brown et al[8] for tetrapolar measurement, but the use in getting a focused effect is novel.

The basic measurement method for this new four-electrode FIM technique is explained with the help of Fig.1, where p, q, r, & s are placed at the corners of a square region 'O', which is the focused zone of interest. Firstly a sinusoidal alternating current of constant amplitude, I, (at tens of kHz, typically) is driven through electrodes p & q while the potential amplitude V_{rs} is measured across electrodes r & s. Next, the same current is driven through electrodes q & r while the potential amplitude V_{sp} is measured across electrodes s and p. Equipotential lines a_1b_1 and c_1d_1 passing through the measuring electrodes r & s respectively for the first measurement enclose the region whose impedance is reflected in the measured value. Similarly equipotential lines a_2b_2 and c_2d_2 passing through the measuring electrodes s & p respectively for the second measurement enclose the region whose impedance is reflected in the measured value. The respective impedances are, $Z_1 = V_{rs} /I$ and $Z_2 = V_{ps} /I$. Now the sum $Z_T = Z_1+Z_2$ of these two impedances will have a dominant contribution from the central common zone, thereby producing the desired focusing effect. Sensitivity mapping using a 2D phantom containing saline in which an insulating cylindrical object was immersed at various 2D points, supported the expectation and established this technique. Fig 2 shows a block diagram of the instrumentation employed for such measurements where alternating current is passed through two adjacent electrodes and potential is measured across the rest two as described above, and the process is then rotated through 90^0.

The present work was taken up in order to obtain sensitivity maps and to study the degree of focusing for objects of different conductivity.

Method:

Phantom

This study used a 2D phantom which basically consists of a square plastic tray with inside dimensions 28 cm × 28 cm, maintained horizontally, and was filled with a shallow layer (1.2 cm deep) of saline,. This essentially acts as a 2D area conductor. Four electrodes were fixed at the centre of the tray at the corner of a square region of side 3 cm each, which is the assumed focused zone. The positions of these electrodes are shown schematically in Fig.3 with blank circles (p, q, r & s). Therefore in this arrangement, the area defined by these four points with co-ordinates (0.5, 0.5), (-0.5, 0.5), (-0.5, -0.5) & (0.5, -0.5) with centre at (0, 0) represent the focused zone of interest. A metallic pin driven vertically into the base at g within the tray but outside the study region acted as the common point for differential potential measurement as described above.

Equal square areas numbering 25 (=5 x 5, including the central zone), each of 3 cm side, were marked out around the central region in the tray. The dots in Fig 3 represent the centres of the adjacent square regions. To study the sensitivity due to the insertion of objects with different conductivities at different positions, cylindrical objects were dipped into the saline, at the centers of all these marked square regions. These centers have been assigned coordinates 0, ±1, and ±2, respectively on both X and Y axes. The focusing effect was studied through analysis of measured impedance values in two orthogonal directions as described in the previous section.

Sensitivity Measurement

With only saline in the phantom, firstly the focused impedance Z_T ($=Z_1 + Z_2$) was measured which gives a reference data for a uniform conductivity distribution. Then a small cylindrical insulating object of 2.2 cm diameter was placed in each of the 25 points mentioned before (Fig.2) and for each of these placements, the respective impedances (Z'_T) were measured. The differences ΔZ_T ($= Z'_T - Z_T$) between each of these measurements and that of the reference gave the sensitivity for the particular placement which were later normalized to the sensitivity of the central region. The system is basically symmetric orthogonally, however, due to asymmetric placement of the common electrode and experimental error small differences were observed. The values at symmetric positions were averaged out to obtain a symmetric sensitivity map.

The same procedure was repeated using a metallic conductor and an organic conductor (a piece of potato cut to shape and size as required) each having the same cylindrical shape and size. The measured sensitivities for three different objects were then displayed in 2 dimensional sensitivity maps.

Results and Observations

The sensitivity map of Fig 4 shows a focusing effect in the central zone for the insulating object. The neighbouring squares in the vertical and horizontal directions have average sensitivities of 22% of that at the center, and at other locations the sensitivities are negligible. Some of the outer zones appear to have an inverse sensitivity which is a common feature in any four electrode impedance measurement, and cannot be avoided. However, these inverse sensitivity values are small, at less than 7%. In Fig.5 for the conducting object, the neighbouring squares in the vertical and horizontal directions have average sensitivities (here –ve) of 13% of that at the center while at other locations the sensitivities are negligible, at less than 2%. The inverse sensitivity (here +ve) occurs at fewer locations and are also negligible, at less than 2%. In Fig.6 for the object with intermediate conductivity, the neighbouring squares in the vertical and horizontal directions have average sensitivities of 10% and negligible sensitivities at other locations, at less than 2%. The inverse sensitivity occurs at still fewer locations and are small, at less than 7%.

Discussion

The four electrode focused impedance measurement is a new technique developed by us earlier, and the focusing effect obtained for the three different objects in the present work further demonstrated the success of this technique. The sensitivity reduced to about 22%, 13% and 10% in the adjacent squares for the three types of objects as indicated above, and to negligible values further out. The inverse sensitivities in the outer zones were also small, less than 7% for all the three objects studied. Therefore this new technique may be useful in many applications as in medicine where an approximate focusing is desired.

The differences in the average sensitivity values, namely, 22%, 13% and 10% observed for the adjacent regions for the three objects studied may be ascribed to the amount of perturbation produced in equipotential lines after an object is introduced into the saline in the phantom. The difference between the conductivities of saline and the insulator would be higher than the same between saline and the conducting object, and therefore, the perturbation is expected to be greater in the former case. This may explain the increased sensitivity of 22% in the adjacent region for the insulator compared to 13% for the conductor. The difference of conductivity between saline and the organic conductor (potato) is expected to be the lowest out of the three, and therefore, expected to give less perturbation and the best focusing, which has also been observed.

Regarding inverse artifacts, as mentioned above, these are limited to only a few zones in the sensitivity map in the case with organic conductor though these appear in more zones in the other two cases. The difference between the conductivity of the saline and the object may again be the cause for this observed difference. However, establishment of the above arguments would need further study, both theoretical and experimental.

In Fig.5 for the conductor the sensitivities have a negative sign which is appropriate since the conductivity of the object is opposite to that of the insulator used to obtain Fig.4, with respect to the conductivity of saline used in the phantom (which forms the reference). In Fig.6 for potato, the sensitivities have a positive sign which is appropriate since the conductivity of potato would be in the same direction to that of the insulator with respect to the conductivity of saline as the reference medium.

In all the three cases, the focusing effect is clearly demonstrated in 2D, and the inverse artifacts have low values that can be ignored for actual measurement situations in human bodies. It needs to be studied further to understand the sensitivity pattern in 3D as most of the real applications of this technique are expected to be in 3D. Being simple, this method may also be modified for multifrequency measurements which may help study certain tissue abnormalities happening in cancerous or other conditions. The advantages of four-electrode FIM system are that it can be fabricated at relatively low costs and has no known significant hazard. Moreover, the system can easily be adapted for dynamic functional studies.

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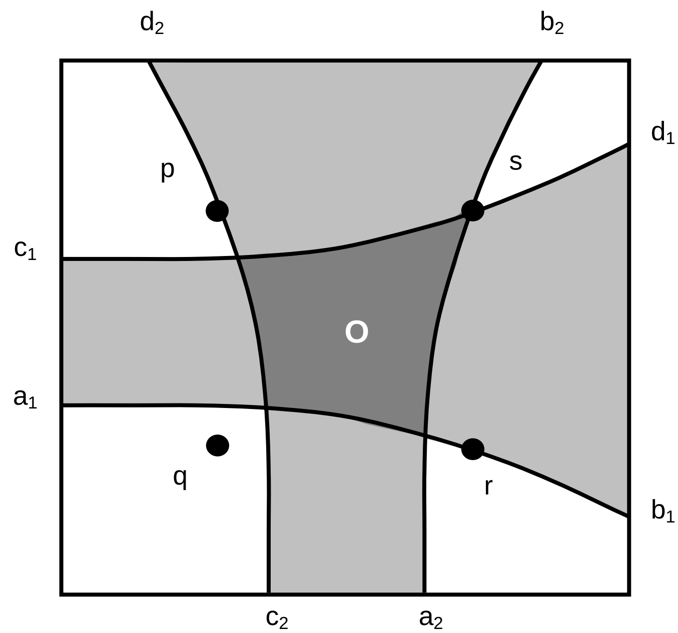
LIST OF FIGURE CAPTIONS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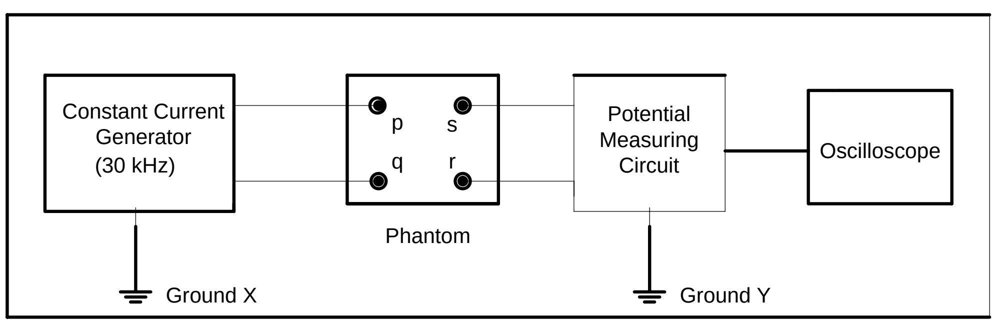
b2
d1
p
s
c1
O
a1
q
r
b1
c2
a2

Fig. 1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p
s
q
r
Phantom
Potential Measuring Circuit
Oscilloscope
Ground X
Ground Y

Fig 2

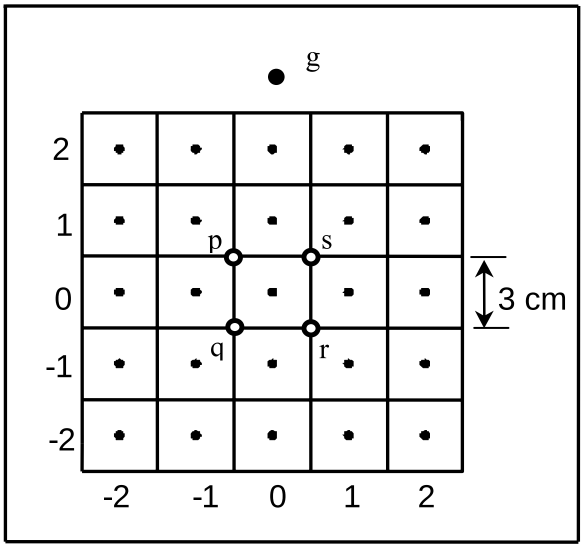

Fig. 3

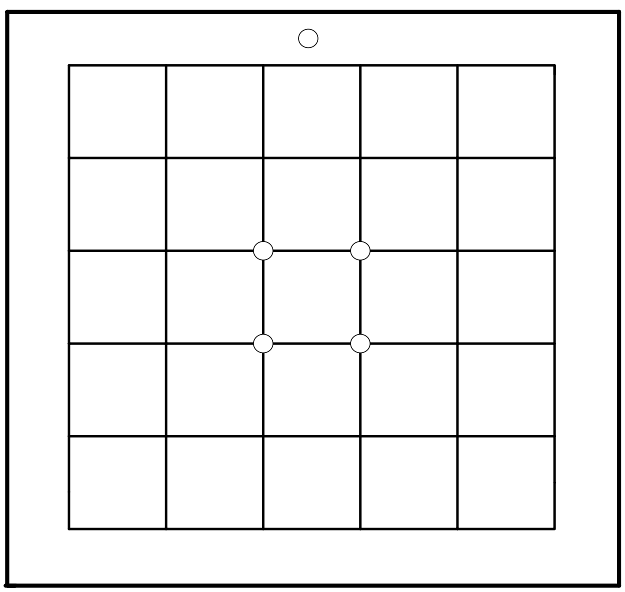

Fig 4

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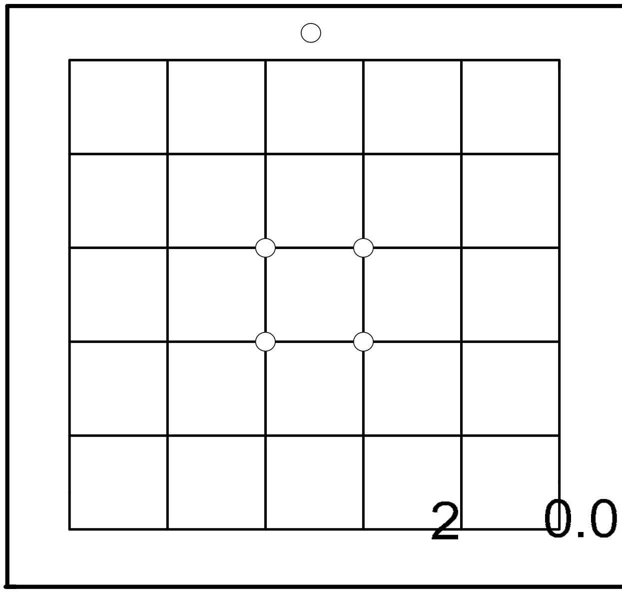

Fig 5

g

	-2	-1	0	1
2	0.05	[illegible]	-0.02	-0.02
1	-0.02	0.02	-0.13	0.02
0	-0.02	-0.13	-1.0	-0.13
-1	-0.02	0.02	-0.13	0.02
-2	0.05	-0.02	-0.02	-0.02

p s

q r

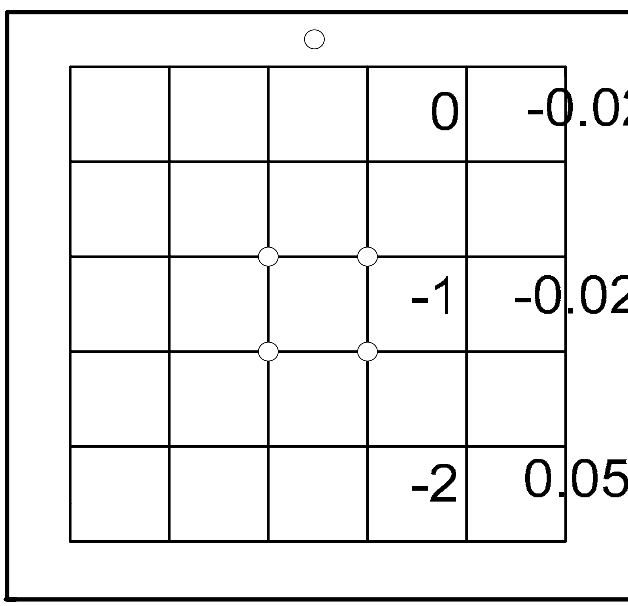

Fig 6