Focused Impedance Method (FIM) and Pigeon Hole Imaging (PHI) for localized measurements – a review

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Abstract. This paper summarises up to date development in Focused Impedance Method (FIM) initiated by us. It basically involves taking the sum of two orthogonal tetra-polar impedance measurements around a common central region, giving a localized enhanced sensitivity. Although the basic idea requires 8 electrodes, versions with 6- and 4-electrodes were subsequently conceived and developed. The focusing effect has been verified in 2D and 3D phantoms and through numerical analysis. Dynamic stomach emptying, and ventilation of localized lung regions have been studied successfully suggesting further applications in monitoring of gastric acid secretion, artificial respiration, bladder emptying, etc. Multi-frequency FIM may help identify some diseases and disorders including certain cancers. FIM, being much simpler and having less number of electrodes, appears to have the potential to replace EIT for applications involving large and shallow organs. An enhancement of 6-electrode FIM led to Pigeon Hole Imaging (PHI) in a square matrix through backprojection in two orthogonal directions, good for localising of one or two well separated objects.

1. Introduction  
Although Electrical Impedance Imaging (EIT) attempts to give images with pixel level resolution [1], such images are not always necessary. In many applications like the study of stomach emptying, lungs functional study, etc., a region of interest is usually marked out in the EIT image and the time progression of the sum of all the pixels within the region is followed for a dynamic study [2]. In some applications a single target object may be studied at different frequencies if its impedance has frequency dependence, at a significant difference from that of the background [3]. For the study of such single target applications a family of localised impedance measurement techniques having the capability of isolating a target object from its neighbours was conceived and developed by the author’s group at Dhaka University, Bangladesh [4][5][6]. This work has recently been taken up by University of Warwick, UK [7] and Kyung Hee University, Korea [8], and the state of development so far is reviewed in this paper.

2. 6-electrode Focused Impedance Method (FIM)  
The idea originated from placing two traditional Tetrapolar Impedance Measurement (TPIM) systems orthogonally around a region of interest as shown in figure 1 where A-A’ and B-B’ are the two orthogonal current drive electrodes. In a further step of innovation, two potential electrodes, u and v, placed diagonally in the central region, replace the four potential electrodes [4] that would have been required for the two TPIM configurations. Respective horizontal and vertical equipotential lines through u and v are shown as straight lines for simplicity. Figure 1 also shows a simple admittance matrix model where the shown admittances (Y_{11} to Y_{33}) are assumed to be isotropic, and contributions
of zones outside are ignored. Measurement through current drive pair AA’ will give the admittance $(kY_{21} + Y_{22} + kY_{23})$ where $k$ is a constant factor, usually less than 1, which takes care of the sensitivity differences between the central zone and the outer ones. Similarly for measurement through the current drive pair BB’, the admittance is $(kY_{12} + Y_{22} + kY_{32})$. An algebraic addition of the two measurements gives the total measured admittance as $Y_T = 2Y_{22} + k(Y_{21} + Y_{23} + Y_{12} + Y_{32})$. Since $k<1$, the central zone has more than twice the sensitivity of the outer ones. Thus the central zone will dominate in the combined measurement and it may be said to be 'focused'. In a practical situation if only $Y_{22}$ changes because of a physiological activity, then $\Delta Y_T = 2\Delta Y_{22}$ and the contributions of the other regions would be eliminated. If one of the admittances $Y_{21}$, $Y_{23}$, $Y_{12}$ or $Y_{32}$ changes simultaneously, its contribution will be much less than $2\Delta Y_{22}$. Studies on a 2D saline phantom showed a success in the focusing effect as expected, albeit with some asymmetrical smearing.

![Figure 1. Basics of FIM and simplified admittance model](image1)

![Figure 2. Basic idea of 4 electrode FIM and the focused zone at the centre.](image2)

3. 4-electrode FIM

Another simpler version of FIM was developed subsequently [5] using 4 electrodes (1 to 4) at four corners of a square region as shown in figure 2. Firstly current is driven through electrodes 1-2 and potential is measured across electrodes 3-4. The region between equipotentials $A_1$-$B_1$ and $C_1$-$D_1$ would be the sensitive zone in this measurement. Next the current is driven through electrodes 2-3 and potential is measured across electrodes 4-1 when the sensitive region would be that between equipotentials $A_2$-$B_2$ and $C_2$-$D_2$. When the two impedance measurements are added, the dark shaded central region would have a dominant contribution similar to that for the 6-electrode FIM discussed before. The measurement may be improved further by rotating the measurement sequence and summing all the values. A 2D phantom study also demonstrated a focusing effect as expected.

4. Numerical Analysis

Numerical analysis at Warwick University, UK, using Geselowitz’s lead field method has confirmed the focusing effect of all the three FIM versions – having 8, 6, and 4 electrodes [7]. A maximum in the average sensitivity of a plane was observed at $1/3$ of the drive-receive electrode spacing for all the three configurations. Negative sensitivity regions down to $1/3$ of the drive-receive electrode spacing was observed for the 4 electrode system while these were down to $1/2$ of the drive-receive electrode spacing for the others. The depth at which the positive peak beneath the electrodes became dominant occurred at 0.7, 1.25 and 0.15 of the receive electrode spacing for the 8, 6 and 4 electrode configurations respectively.

5. Physiological applications of FIM

FIM was applied to study gastric emptying after a drink of saline, placing electrodes on the frontal surface[4] and the result is shown in figure 3. Region of interest marked around the stomach in EIT studies [4][9] have shown an exactly similar behaviour. In lung ventilation studies normal healthy subjects took a deep breath and then expired a little air at a time in steps and held the breath for a short while each time. During the breath holding period, FIM data were recorded for the lower right
lobe of the lungs from the front and simultaneously corresponding volume of air expired was measured using a bellows type spirometer. From the above data, percentage change in focused impedance and change in air volume, with reference to the values at total expiration, were calculated. Figure 6 shows a very good correlation between these parameters [10]. Similar localised lung FIM measurement from different subjects having different Vital Capacity (VC - total air volume expired on forced expiration following deep inspiration) showed an almost linear relationship with VC. This shows the utility of FIM in measuring lung ventilation, particularly in identifying localised ventilation disorders.

FIM may replace many investigation of large organs that have been proposed with 2D EIT through region of interest analysis. These include gastric emptying, gastric acid secretion, lungs ventilation and perfusion, monitoring of artificial repiration, bladder emptying, etc. Multifrequency FIM may have application in the diagnosis and detection of pneumonia and of cancerous tissues at shallow depths, including cervical and oral cancers. Success in detecting cervical cancer using tetrapolar arrangement [11] suggests that FIM may also be successful in this application. Besides, FIM may be used in the measurement of tissue temperature in radiotherapy, and in monitoring of cancerous tissue ablation in non-reversible electroporation [12].

7. Pigeon Hole Impedance Imaging (PHI)

By extending the concept of the 6 electrode FIM the PHI technique was developed for providing a crude image, in the configuration of a pigeon hole [6]. Figure 5 shows an example with four diagonal potential electrodes which have replaced the two in 6-electrode FIM. In a simplified admittance model as shown in figure 6, combinations of current drives and potential measuring pairs give the total row
and column admittances ($\Sigma Y_{1j}$ to $\Sigma Y_{3j}$, $\Sigma Y_{i1}$ to $\Sigma Y_{i3}$). Backprojections of these measured admittances along the two orthogonal directions will give values in which each of the matrix admittances will dominate, such as $Y_{11} \approx (\Sigma Y_{1j} + \Sigma Y_{i1})/3$, $Y_{12} \approx (\Sigma Y_{1j} + \Sigma Y_{i2})/3$, etc., thus giving the individual pixels of the ‘image’. Experimental study using saline filled 2D and 3D phantoms gave the locations of a single object successfully. PHI can only be expected to differentiate objects that are widely separated, and mostly it would be useful in locating a single organ of interest in an individual.

8. Discussion
As mentioned in the beginning, in many applications a single organ is often the object of interest for which a sophisticated imaging system like EIT is not needed, and the focused impedance systems including PHI fill an important gap. Being simple in methodology and instrumentation the costs will be significantly lower compared to EIT systems, besides, having much less number of electrodes to manage, these systems offer additional advantages in terms of robustness and ease of application. The family of FIM’s presented in this review may find potential clinical application sooner than EIT because of their simplicity. These would particularly be suitable for the Third World as the instruments can be designed and made locally thus making them affordable and sustainable for widespread use, benefitting a large number of people globally.

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10. References
[1] Barber DC, Brown BH and Freeston IL 1983 Electron. Lett. 19 933-5
[2] Harris ND, Suggett AJ, Barber DC and Brown BH 1987 Clin. Phys. Physiol. Meas. 8 (Suppl. A) 155-65
[3] Brown BH, Barber DC, Wang W, Lu L, Leathard AD, Smallwood RH, Hampshire AR, Mackay R and Hatzigalanis K 1994 Physiol. Meas. 15 (Suppl. 2 A) 1-11
[4] Rabbani KS, Sarker M, Akond MHR and Akter T 1999 “Electrical Bioimpedance methods”, Annals of the New York Academy of Sciences, 873 408 - 20
[5] Rabbani KS, and Karal MAS 2008 Annals of Biomedical Engg. 36 1072-77
[6] Afroj K, Alam N, Rahman M and Rabbani KS 2004 J. of Bangladesh Medical Physics Association, 3 7-13
[7] 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
[8] Wi H and Woo EJ 2009 10th International Conference on Biomedical Applications of Electrical Impedance Tomography (EIT2009), http://www.maths.manchester.ac.uk/eit2009/abstracts/wi1.pdf
[9] Avill R, Mangnall YF, Bird NC, Brown BH, Barber DC, Seagar AD, Johnson AG and Read NW 1987 Gastroenterology 92 1019-26
[10] Kadir MA, Baig TN and Rabbani KS, Proceedings, 10th International Conference on Biomedical Applications of Electrical Impedance Tomography (EIT2009), http://www.maths.manchester.ac.uk/eit2009/abstracts/kadir.pdf
[11] Brown BH, Tidy JA, Boston K, Blackett AD, Smallwood RH and Sharp F 2000 The Lancet 355 892-895
[12] Rubinsky P, Onik G and Mikus P 2007 Technol Cancer Res Treat, 6 37-48.