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Improving the Sensitivity at the Center of Lung by using Focused Impedance Method

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Abstract
Lung diseases like Pneumonia, Tuberculosis, Pulmonary edema, and Lung cancer are the main causes of death, specially in the third world countries. Most commonly used lung disorder detection methods are X-Ray, MRI and CT scan which are costly and complex; and these are not available widely in countries like ours, particularly in the rural areas. Therefore, in most of the cases the problem remains undetected or undiagnosed. Recently, electrical impedance methods have come up with a promise to provide low cost detection and diagnosis of lung disorders. An age old method of Tetrapolar Impedance Measurement (TPIM) cannot localize a particular area of the lungs well. On the other hand, Electrical Impedance Tomography (EIT) has been used successfully in lung measurement but it has a very complex configuration which uses many electrodes and the system is also very expensive. A recent innovation named Focused Impedance Method (FIM) by a Dhaka University group has the potential of being simple on one hand, while allowing focusing of a localized zone of interest. In our study, our main aim is to determine sensitivity at the lung area for electrodes on both sides of the body so that abnormalities can be localized, detected and diagnosed. Simulation was done using Comsol multiphysics.

Key words: Electrical Impedance Tomography (EIT), Tetrapolar Impedance Measurement (TPIM), Focused Impedance Method (FIM)

I. Introduction

Health monitoring, detection and diagnosis of diseases and disorders are very important to live a healthy life. If these are done properly, we can find out the causes of diseases which may lead to proper treatment. Lung is one of the vital organs of human body. Different diseases which affect lung are -Pneumonia, Tuberculosis, Pulmonary edema, Lung cancer, Pleurisy. Different devices which are used to detect lung abnormalities are- stethoscope, spirometer, CT (Computed Tomography) a gamma camera (γ-camera). All these equipments have certain advantages and disadvantages. Researchers all over the world are trying to find cheaper, simple and non-invasive techniques to localize and detect lung diseases more precisely.

Recently, electrical impedance metphods have come up with a promise to provide low cost detection and diagnosis of lung disorders. A group in Sheffield, UK shows a remarkable enhancement in the field of electrical impedance. They applied potential tomography which gives a 2D image (Frerichs *et al.,* 2003, Barber *et al.,* 1985). It essentially gives an image of a section of the body with many electrodes around. Typical numbers of electrodes are: 8, 16, 32 and 64 in a plane for 2D EIT. However, the measurements performed are basically TPIM, using four specific electrodes chosen from the electrodes. EIT devices yield an evaluation of regional lung aeration and tidal volume and allow assessment of immediate, consequences of a change in ventilation or other therapeutic intervention (Wagenaar & Adler 2016). Tetrapolar Impedance Measurement (TPIM), which uses four electrodes, and is a reasonably simple technique, but it cannot localize a particular area of the lungs well. A four-electrode or Tetrapolar Impedance Measurement (TPIM) scheme was introduced to eliminate the contribution of the skin-electrode contact impedance, making it only dependent on the bulk impedance. On the other hand, Electrical Impedance Tomography (EIT) has been used successfully in lung measurement but it has a very complex configuration,

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which uses many electrodes and the system is also very expensive. A recent innovation named Focused Impedance Method (FIM) by a Dhaka University group has the potential of being simple on one hand, while allowing focusing of a localized zone of interest. A new technique, known as 'Focused Impedance Method (FIM), has been innovated at the University of Dhaka, which is marginally complex than TPIM but providing improved zone localization. Thus it comes as a bridge between TPIM and EIT. It essentially consists of the sum of two orthogonal Tetra polar Impedance Measurements (shown in figure 1). The negative sensitivity zones are less than that in TPIM. Therefore, FIM offers an advantage by being focused and simple.

The electrode configurations may be varied to focus different zones of the body. FIM has prospective applications in many physiological studies and in the detection and diagnosis of diseases and disorders of the human body (Rabbani & Kadir 2011). FIM consists of basically the sum of two orthogonal Tetra polar Impedance Measurement (TPIM) systems placed symmetrically around a central zone (Rabbani *et al.*,2009 ,Haowlader *et al.*,2010). In this study, we measure the sensitivity in different regions of the lung area so that abnormalities can be localized, detected and diagnosed using 4 electrodes FIM.

The principle of electrical impedance is based on the measurement of electrical voltages at the surface of the thorax, resulting from applications of small electrical currents to the body. The electrical properties of the lung tissue differ significantly from those of other thoracic tissues and, moreover, vary quasi-periodically with ventilation, infection, and edema. For this reason, electrical impedance scanning is particularly suitable for assessing the lung function [Geddes & Baker 1967].

Application of electrical impedance is still under research. Bio impedance analysis is very recent topic in biomedical engineering. Researchers all over the world are still working to improve the procedure.

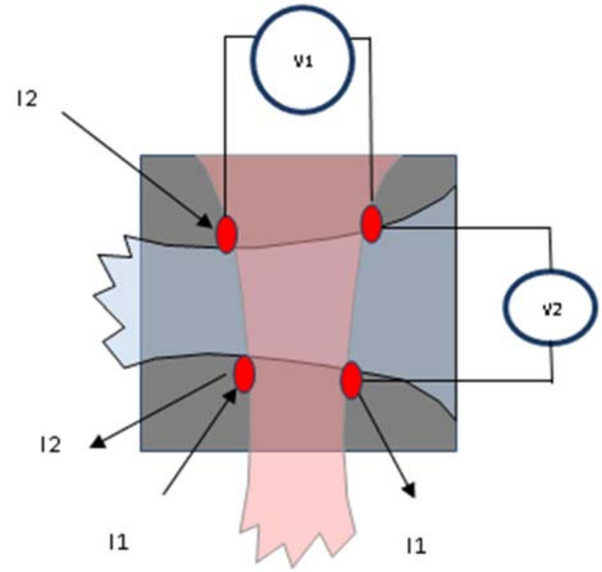


Figure 1: Four Electrodes FIM

All electrical impedance techniques are particularly sensitive and useful if the electrical impedance of a target object in the sensitive zone changes between two sets of measurements. Lung is such an organ. On inhaling air, the inside of the lung has more air, increasing the impedance. On breathing out, the inside of the lung has less air, decreasing the impedance. In previous TPIM or FIM studies of lungs, it was carried out from one side of the body. In such a configuration, the depth of sensitivity is small (Rabbani *et al.,*1998). So these are useful for measuring organs at shallow depths. To detect any changes in a deep seated and large organ like lungsone sided TPIM or FIM is rather restricted. So the present proposal would try to study newer configurations of electrodes for measurements of TPIM and FIM on the thorax to give a greater sensitivity in the lung region, deep inside the body.

II. Methods and Measurements

FIM measurements were carried out using Comsol multiphysics. Fine mesh analysis is used where maximum element size is 2.64 cm and minimum element size is 0.33 cm. Frequency was set 1kHz using a water (tap water) filled 3D box, made of transparent acrylic, of dimension 33cm x 26cm x 12m (as schematically depicted in figure 2 and 3).This configuration gives thick section of thorax that includes lungs. Conductivity of water is 0.054 S/m(tap water) and relative permittivity is 80.Stainless steel electrodes were placed on both side of the box. They are placed on one part of the box which can cover one lung .Conductivity of Stainless steel is 2000000S/m and relative permittivity is 1.The spacing of the electrodes in each pair was 15cm which is related to the size of the lung. Size of the electrodes was 3 cm long and diameter of the electrodes was 0.03cm.

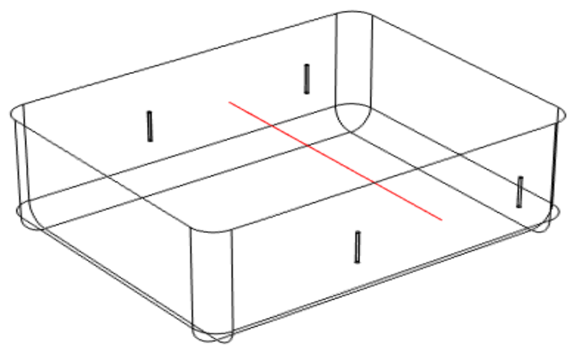


Figure 2: Sensitivity along the width of the box

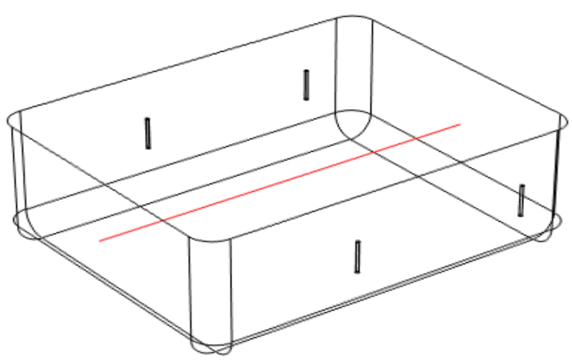


Figure 3: Sensitivity along the length of the box

TPIM 1 and TPIM 2 measurement system is given in figure 4. Combining this two we get an FIM configuration. In this configuration focused zone is expected to increase as electrodes were placed on both sides. We have measure sensitivity at the center position of the box which gives us idea how the impedance will vary for any abnormalities.

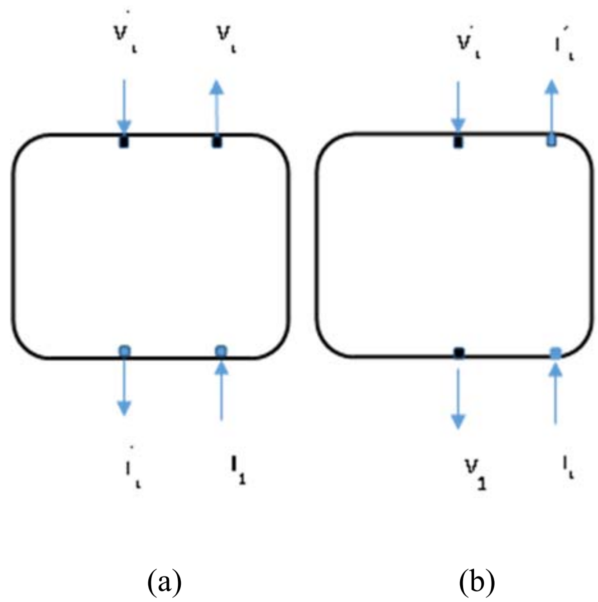


Figure 4: (a):Tetrapolar Impedance Method 1 (TPIM1 (b): Tetrapolar Impedance Method 2 (TPIM2)

III. Results and discussion

In this study FIM was done combining two TPIM configurations shown in figure 4. We have measured the sensitivity at various positions using COMSOL multiphysics. Electrodes were placed at 13 cm and 28cm distance from the left side. For TPIM 1 connection sensitivity is higher close to the electrodes. As we move towards the center, sensitivity decreases. (shown in figure 5) For TPIM 2 connection sensitivity is negative close to the electrodes. It gradually increases as we move towards the center. At the center it becomes highest. Adding both the values, we find that sensitivity is quite high at the center (shown by solid line in figure 5). Figure 6 shows the sensitivity distribution in color. Sensitivity close to the electrodes is very high showed by the dark region. For TPIM 1 there is a negative sensitivity region outside the electrodes covered area. For TPIM 2 negative sensitivity region between the two same side electrodes is very high. In our figure we showed the range from -400 to 2000.Combining both TPIM1 and TPIM2, FIM sensitivity distribution is observed (shown in figure 6(c))

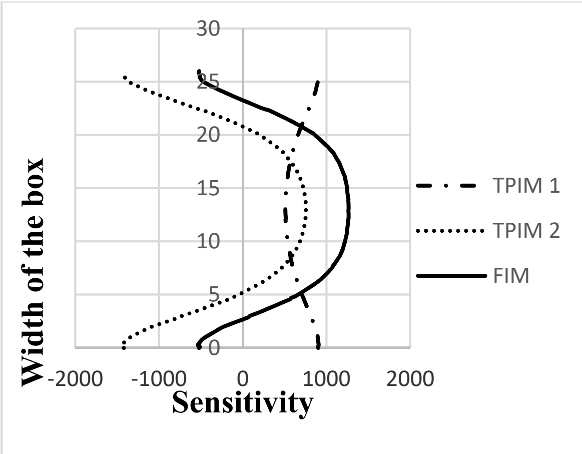
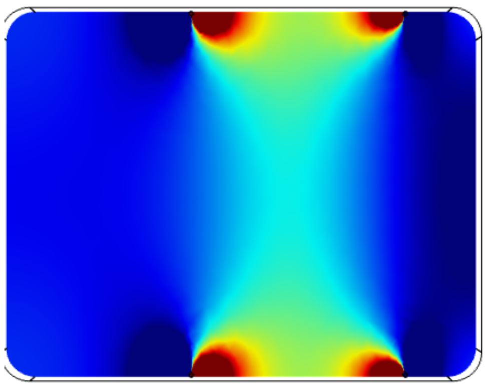
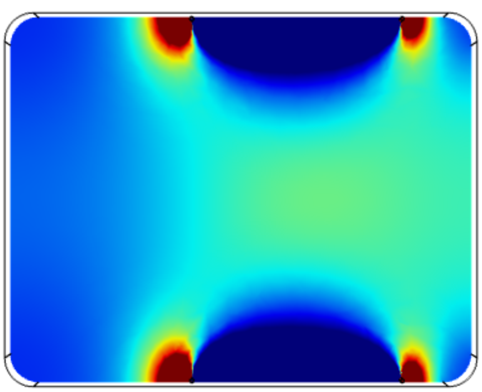


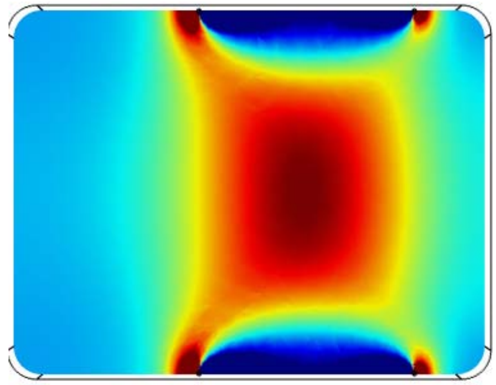
Figure 5: Comparison of sensitivity at the center.



(a)



(b)



(c)

Figure 6 (a): Distribution of sensitivity of TPIM1

(b): Distribution of sensitivity of TPIM2

(c): Distribution of sensitivity of FIM

From the above graph sensitivity at the center position (20.5cm) between the electrodes were shown along the width of the box. For TPIM 1 configuration where two electrodes at the same sides were working as terminal and ground sensitivity decreases at the center gradually. Highest sensitivity is around 850 and lowest sensitivity is around 500. For TPIM 2, where terminal and ground electrodes were placed on both sides sensitivity is negative besides the electrodes then it gradually becomes positive and reached its peak at the center. Highest sensitivity is around 750 at the center. Adding both the TPIM 1 and TPIM 2 we get sensitivity at the center around 1200 which is quite high compare to the one side electrodes used previously. Figure 7 shows the normalized values of the configuration.

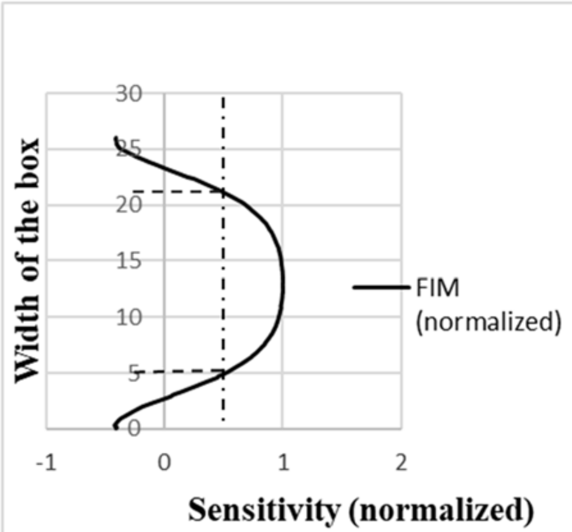


Figure 7: Normalized sensitivity along the width.

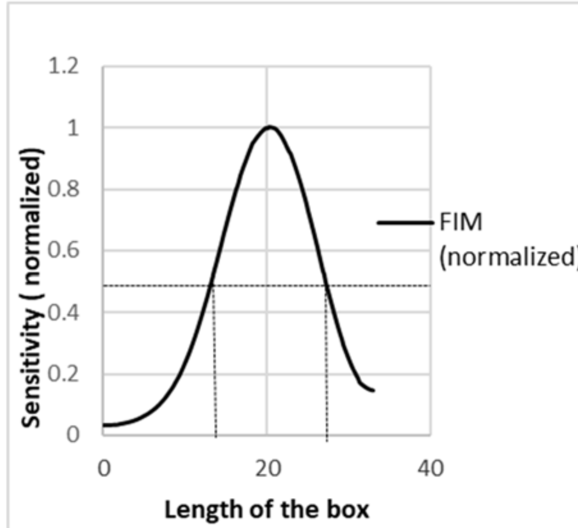


Figure 9: Normalized sensitivity along the length.

Along the length of the box sensitivity is negative for TPIM 1 configuration besides the central zone between the electrodes. It reaches its highest value at the center which is around 20-21 cm then it again become negative outside the central zone. For TPIM2 configuration sensitivity remain positive for all position. In this case sensitivity at the center is quite high. Adding both the values we get quite high sensitivity at the center around 1300.

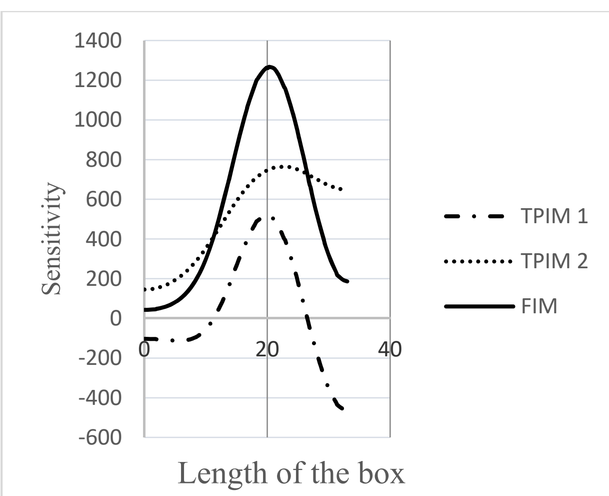


Figure 8: Comparison of sensitivity along the length.

IV. Discussion and Conclusion

A visualization of the depth sensitivity may be obtained from figure 7 and 9. In the normalized graph (figure 7), FWHM (full width at half maxima) of the width is around 16cm at the center. This length may cover the almost full thickness of the lung. In the Figure 9, FWHM is around 15cm which is the separation between the electrodes. This configuration can improve the sensitivity at the lung part significantly i.e. any change in impedance due to any abnormality in lung can be detected by this configuration.

Lung which is one of the vital organs of human body is affected by many diseases. If the diseases detect at proper time many of these diseases are fully recovered. Medical devices which are most commonly used to detect the lung disorder are not cost effective and take large area for installation. On the other hand, Electrical impedance technique is cost effective and easily portable, especially suitable for rural area.

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