Kalman Algorithm Based Electrical Impedance Tomography Imaging

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Abstract—Electrical Impedance Tomography (EIT) is a non-invasive imaging technique that displays changes in conductivity within a body. This method finds applications in biomedical and geology. EIT finds use in biomedical applications, as the different tissues of the body have different conductivity and dielectric constants. In this paper a phantom model is designed considering Finite Element Model (FEM). AC current of amplitude 1 mA and frequency 1 KHz is applied considering adjacent protocol with noise less and noisy cases. From the computed voltage data image is reconstructed using Kalman algorithm. For noisy case noise levels equal to Signal-to-Noise Ratio (SNR) 30 dB, 15 dB and 7 dB were considered. Kalman algorithm is studied for EIT image reconstruction in noise free and noisy case, in terms of shape, size, spatial location of the target object.

Index Terms—Electrical Impedance Tomography; Kalman Algorithm; Conductivity.

I. INTRODUCTION

Non-destructive imaging systems have experienced a great technological development in last few decades, allowing the evolution from planar image to full 3-D reconstructions, from static images to dynamic and functional ones. It is a growing field, with each year bringing new imaging systems, improvement of older ones, new numerical techniques, all of them with a wide spectrum of applications, making it a very interesting and appealing area of knowledge [2]. Electrical Impedance Tomography (EIT) is a promising biomedical imaging technique. The basic principle of this method is the repeated measurement of surface voltages of a body, which are a result of rolling injection of known and small-volume sinusoidal AC current to the body through the electrodes attached to its surface and reconstructing conductivity images from the measured data [1]. The electrical properties of human body tissues made it possible to reconstruct the conductivity images and retrieving the information of the interior of the body.

A. Motivation to EIT

EIT was proposed in 1978 by Henderson and Webster [3], but the first practical realization of a medical EIT was due to Barber and Brown [4]. EIT offers several advantages compared to traditionally used imaging techniques such as it is non-invasive imaging technique, does not use ionizing radiation, can be performed at the bedside and provides continuous information [5]. According to Bayford 2006 [6] EIT has a high temporal resolution since it operates at 10-50 images per second. But still EIT is not yet adopted for

regular use in clinical applications. According to Frerichs *et al.* 2017 [5] continuous assessment of regional body function using EIT in critically ill patients has recently received much research interest.

EIT was identified as a potentially promising thoracic imaging technology early in the development of EIT systems, as from Brown *et al.* [4], even though it suffered from low spatial resolution. Again for brain activity monitoring fMRI is currently the method of choice to non-invasively image reconstruction of distinct brain areas. Rather than direct activity, from Ogawa *et al.* 1990 [7], fMRI measures the epiphenomenal blood flow. EEG can image direct neural activity over large regions of the brain, but it has a low spatial resolution [13] and is blind to dipole sources oriented tangentially to recording electrodes. Currently no satisfactory method exists to record direct neural activity occurring over large regions of the brain. EIT imaging has the potential to image neural activity occurring on the millisecond time scale throughout the brain [8].

The increasing sophistication of monitoring intensive-care patients might incorporate the use of EIT system to guide strategies for protective lung ventilation via the close monitoring of patient's lung. Although EIT cannot compete with CT, MRI or ultrasound in terms of spatial resolution or accuracy, its ability to provide long-term, continuous monitoring and portability make it clinically useful [9]. In [10] a proposed method is tested in numerical simulations, phantom experiments and human experiments for monitoring patient's lung using EIT. Breast cancer is a warning concern in recent era. EIT is a new potential breast cancer screening or pre-screening method to detect malignant tumors at early stage [12]. In this regard, it is suggested to call it Electrical Impedance Mammography (EIM). In [11] a recent experimental result demonstrates that an EIM system with the new design achieved a high output impedance of 10 M Ω at 1 MHz to at least 3 M Ω at 3 MHz frequency, with an average SNR and modelling accuracy of over 80 dB and 99%, respectively. So EIT is a most promising medical imaging technique.

B. Electrical Properties of Biological Tissues

The core physical principle of EIT is the possibility to differentiate between biological tissues by their conductivity, which relates to their passive electrical properties [14]. Determination and measurement of the electrical properties of biological tissues has a key role in the evolving field of bio-impedance and bio-electricity [15]. The body is considered as a complex volume-conductor, consisting of a spatial distribution of tissues, each type having its unique electrical properties. Tissues have both electrolytic and dielectric characteristics, i.e., they behave as electrolytic conductors, with ions free to migrate, and at the same time electric fields penetrate them, displacing bound

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charges. As a result, bio-materials can contain both conductive and capacitive or displacement currents, and can be related to as either electrolytes or dielectrics, depending on which kind of current is more dominant [16]. A tissue is a very in-homogeneous material from an electrical point of view. Table I gives the conductivity and permittivity values of some selected human tissue types at excitation frequencies of 20 KHz, 50 KHz and 100 KHz [17].

TABLE I: CONDUCTIVITY AND PERMITTIVITY VALUES OF HUMAN TISSUES

Tissue	Conductivity σ [S/m]			Relative Permittivity ϵ_r		
	20KHz	50KHz	100KHz	20KHz	50KHz	100KHz
Blood	0.7	0.7	0.7	5236	5197	5120
Interstitial Body Fluid	1.5	1.5	1.5	99	98	97
Bone	0.02	0.02	0.02	362	264	227
Brain Grey Matter	0.12	0.13	0.13	11837	5461	3221
Brain White Matter	0.07	0.08	0.08	7258	3548	2107
Cerebellum	0.14	0.15	0.15	12132	5755	3515
Cerebro-Spinal Fluid	2.0	2.0	2.0	109	109	109
Fat	0.02	0.02	0.02	458	172	92
Deflated Lung	0.25	0.26	0.27	18150	8531	5145
Inflated Lung	0.10	0.10	0.11	9111	4272	2581
Muscle	0.34	0.35	0.36	15521	10094	8089

One could be impressed by the large range of values for the various tissues, which enables the required contrast in a topographic reconstruction. By reconstructing either the conductivity or the permittivity distributions, it is possible to associate each resulting structure in the image having the same reconstructed value with a specific tissue type, thus retrieving an anatomical image.

C. EIT Problem

EIT is a two stages problem, forward problem and inverse problem [18]. In forward problem, a model is considered where the shape, size, impedance distribution within the volume and injected currents or applied voltages are given or defined. This model then computes or estimates the voltages or currents on the surface of the volume at defined points (surface electrodes). Finite Element Model (FEM) and Boundary Element Model (BEM) are two widely used models for solving forward problem. FEM is well formulated and this model is considered in this work [19]. There are two ways to apply electrical energy into the volume. One can apply electrical current through surface electrodes into the volume and measures the corresponding voltages generated due to the impedance distribution within the volume. In the second method, voltage is applied through electrodes and the corresponding currents are measured or computed. The first method is most widely used and in this research work we followed this method. Typically, current is injected through 16 or 32 equally spaced electrodes on the surface of the volume. In first protocol, current is injected in the object through adjacent electrodes and resulting voltages are measured in the rest of the electrodes. In second protocol, current is injected through the electrodes which are 90 degree apart and

voltages are measured in the rest of the electrodes. In third protocol, current is injected through the opposite electrodes and voltages are measured in the rest of the electrodes [21].

In EIT, the inverse problem means reconstruction of electrical impedance or conductivity from the computed or measured data i.e., current and voltage measurement data. To find the electrical impedance distribution within the volume researches developed different types of reconstruction algorithms. Among those followings are most widely used such as Back-Projection (BP) algorithm, Filtered Back-Projection (FBP) algorithm, Gauss-Newton (GN) algorithm, Kalman algorithm and Total Variation (TV) regularized Primal Dual-Interior Point Methods (PD-IPM) algorithm [22]. Moreover, inverse problem in EIT is an ill-posed problem and prior information is needed to provide which is known as regularization [20].

II. METHODOLOGY

To investigate the performance of Kalman algorithm in EIT image reconstruction in two cases, noise free case and noisy case, computer simulations were carried out. Simulated measurements were obtained through the FEM method using a 2-D geometry with circular shape having homogeneous conductivity and containing a circular target object again having homogeneous conductivity but different from background geometry. Simulation measurements were done using EIDORS with MATLAB software. In generating forward model a 2-D circular object (background) is considered with a radius of 1 cm and conductivity of 1 S/m. The inserted target object has a radius of 0.25 cm and conductivity of 1.5 S/m. This 2-D circular model is divided into 576 elements to generate fine mesh.

Although in real life the world is, in most cases, 3-D, it is still interesting to look at 2-D simulations because they are easier to understood and quicker to simulate. It is also intuitively clear that the 2-D case is not too far from the 3-D case. For example considering a cylindrical object placed inside a cylindrical tank with electrodes of the same height as the tank, one essentially gets the 2-D case. Here, only two-dimensional simulation is done with 2-D meshes using the EIDORS software.

Fig. 1. Simulation geometry, (a) Background with homogeneous conductivity (b) Inhomogeneous conductivity.

In order to decide the dimensions of the simulated conductivity model and amount of injected current, several previous studies have been considered [17], [22]. The geometry used here is shown in fig. 1(a). It is a circular FEM model. This FEM model contains 576 elements which actually indicate the mesh density. The circular geometry having radius, $r_1 = 1$ cm. It is referred to as background with conductivity, $\sigma_1 = 1$ S/m. Actual simulation is

performed on geometry shown in fig. 1(b), where a circular target object has been inserted. The object has a radius, $r_2 = 0.25$ cm and conductivity, $\sigma_2 = 1.5$ S/m. Therefore object has a radius which is 25% of that of background geometry and conductivity which is 150% of that of background.

Electrodes used here are point electrodes. There are total 16 electrodes and it is complete electrode model. Since it is 2-D simulation only one ring of electrodes has been used. Simulation is performed for adjacent measurement protocol. Resulting voltage measurement is not carried out at electrodes where stimulation current is applied. So that for adjacent measurement protocol number of measurements available for each stimulation is (16-3) i.e., 13. Again only 16 stimulations are possible; therefore, total number of measurements is equal to $13 \times 16 = 208$. Simulation is again carried out under same conditions described above with three different noise levels equal to SNR 30 dB, 15 dB and 7 dB. The injected current amplitude and frequencies are 1 mA and 1 KHz respectively.

III. RESULTS

The true conductivity image of the designed model is shown in following fig. 2. Fig. 2(a) shows the background with conductivity 1 S/m in fig. 2(b) an impurity with conductivity 1.5 S/m is added and finally fig. 2(c) shows the difference image from fig. 2(b) to fig. 2(a).

Fig. 2. True conductivity image of 2-D model, (a) Background (b) Background with object (c) Difference conductivity image.

The EIT images reconstructed using Kalman algorithm in noise-free and noisy case is shown in fig. 3 and fig. 4 respectively.

Fig. 3. Reconstructed conductivity image using Kalman algorithm for noise-free case.

Fig. 4. Reconstructed conductivity images using Kalman algorithm with (a) SNR 30 dB (b) SNR 15 dB (c) SNR 7 dB.

The results show that, Kalman algorithm is able to generate original shape, size and spatial location of the impurity object. It generates two circular conductivity

regions around the object which are not present in true map. In noisy case, reconstructed images are almost same as in noise free case. As can be seen in fig. 4 output images with noise level equal to SNR 30 dB, 15 dB and 7 dB have almost same quality. This may be an excellent feature of this algorithm. This algorithm is thus less diverged by noise. It is robust against noise and capable to generate better image with high noise level e.g., as low as SNR equal to 7 dB.

Fig. 5 displays the one dimensional conductivity profiles of the true and reconstructed maps. Reconstructed background conductivity is high near the object. This occurs because of the presence of high conductivity object region. The results show that, Kalman algorithm has much better performance in terms of conductivity reconstruction.

Fig. 5. 1-D conductivity profiles.

IV. DISCUSSION AND CONCLUSION

EIT is a most promising biomedical imaging technique. Large difference between different biological tissues makes this technique very much attractive but this technique is still under laboratory research. In this study, Kalman algorithm has been tested for EIT image reconstruction for adjacent measurement protocol. The performance, in terms of shape, size and spatial location of the impurity object is studied. The attractive feature of this algorithm is found that reconstructed image quality is almost invariant of the presence of noise. This algorithm is found robust against noise. Practical clinical applications are noisy case. Robustness of Kalman algorithm against noise and acceptable performance may make it the most suitable for practical applications. Performance of Kalman algorithm for more complex distribution of conductivity and for non conductive object may be studied.

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