Practical Phantom Studies with A Battery Based Electrical Impedance Tomography System

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***Abstract*—Electrical impedance tomography (EIT) is a computed tomographic technique which has been applied for a number of medical investigations. Practical EIT systems need an electronic instrumentation system for current injection and voltage data collection from the patient's body. EIT instrumentation is generally fed by the ac main power supply which must be developed with a number of strictly specified design parameters and must be applied with certain cares for obtaining the better patient safety. To obtain a better patient safety a battery based EIT system developed and studied with practical phantoms. A battery based EIT system is developed with a LabVIEW based EIT instrumentation powered by a battery based power supply. A number of practical phantoms are developed and the resistivity images are studied with battery based EIT system. Signal to noise ratio is improved in battery based EIT system. Results demonstrated that the practical phantoms are successfully reconstructed with battery based EIT system. Results also show that all the phantom domains with different inhomogeneity configurations are successfully reconstructed from the boundary data measured.**

Keywords—Electrical impedance tomography (EIT), battery based EIT, medical imaging, patient safety, practical phantoms, image reconstruction, resitivity imaging.

I. INTRODUCTION

Electrical impedance tomography (EIT) [1-8] is a computed tomographic technique [9-10] which reconstruct the spatial distribution of electrical impedance data of a domain under test from the boundary voltage current data using a reconstruction algorithm [11-15]. Being a fast, noninvasive, radiation free, portable low cost imaging modality, EIT is a computed tomographic imaging modality which has been applied for a number of medical and clinical investigations [16-17]. In medical and clinical studies patient safety [1, 18] is very crucial factor which must be considered before applying a diagnostic technique on patients. Biomedical electronic instruments and health monitoring systems [19-20] powered by ac mains are generally provided with some precautions and patient safety guidelines for it safer application in medical investigations. Practical EIT systems (Figure 1) are developed with an EIT electronic instrumentation system [21-26] required for current injection and voltage data collection from the patient's body through surface electrodes [27-30]. The electronic instrumentation of the EIT system is generally fed by the ac main power supply using a step down transformer and the rectifier-filter circuits. Therefore the EIT instrumentation fed by ac mains must be designed and developed with a number of design parameters which must be followed by the designers should be strictly specified in the instrument data sheet along with the required precautions. Moreover the ac mains powered EIT system must be applied to the patients by taking certain precautions to obtain the better patient safety. Also, medical EIT systems must be studied, tested, evaluated and calibrated with practical phantoms [3, 6, 14-15, 31-40] before applying it to human subjects. In this direction, to provide a better patient safety, a battery based EIT system is developed and studied with practical phantoms. A battery based EIT system is developed with an EIT instrumentation powered by a battery based regulated power supply (BRPS) as shown in Figure 2. A number of practical phantoms are developed with different inhomogeneity configurations and the resistivity images are studied with battery based EIT system. Results demonstrated that the signal to noise ratio (SNR) [41-42] of the boundary potential data is improved in battery based EIT system. It is observed that the practical phantoms with different inhomogeneity configurations are successfully reconstructed from the boundary data measured collected battery based EIT system.

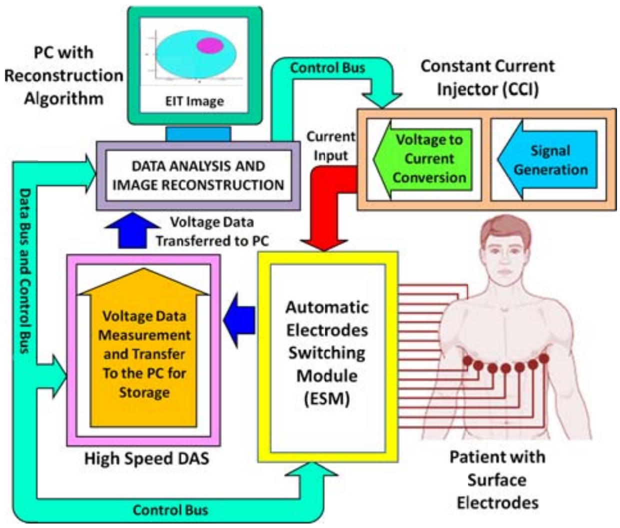

Fig. 1. EIT system schematic with a patient with surface electrodes.

II. MATERIALS AND METHODS

A. Battery Based EIT System

Battery based EIT system is developed with an electronic instrumentation powered by a battery based regulated power supply (BRPS). The EIT instrumentation is interfaced with the personal computer (PC) with a graphical user interface working on LabVIEW [43-45]. LabVIEW based EIT instrumentation is developed with a constant current injector (CCI) [46], an automatic electrode switching module (ESM) and a LabVIEW based data acquisition system (DAS). A battery based regulated power supply (BRPS) is developed with two 12 V sealed lead acid rechargeable batteries and a battery charging circuit module (BCCM) developed for generating a pure ±12 V pure dc power. The BCCM is used for charging the batteries of the BRPS and the BRPS is used to feed the entire EIT instrumentation.

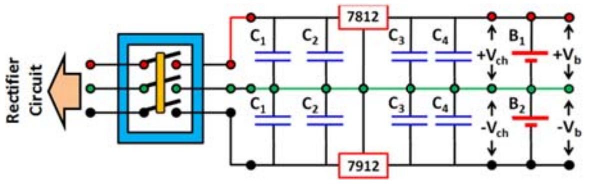

Fig. 2. Schematic of the battery based regulated power supply (BRPS) with filter-regulator-filter (FRF) block.

The BCCM is developed with a filter-regulator-filter (FRF) block developed as per the battery power consumption. The BCCM is fed by the power supply obtained from the bridge rectifier circuit module (BRCM). The battery charging circuit is used for charging the batteries of the BRPS and the charging circuit is kept disconnected when the BRPS is used for feeding the EIT system. The entire analog instrumentation of the developed EIT system (Figure 3) is fed by the BRPS and the EIT current injection and the boundary data collection are performed with a number of practical phantoms.

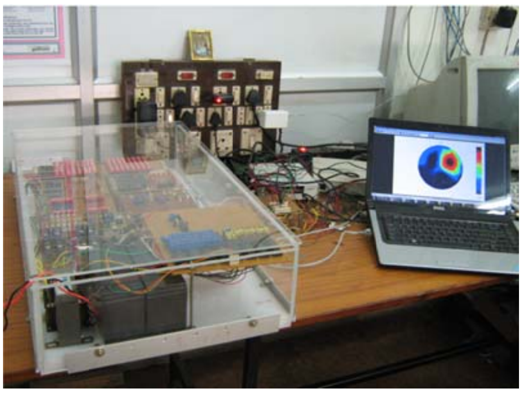

Fig. 3. The complete battery based EIT system.

B. Practical Phantoms

Practical phantoms are developed with glass tanks filled with NaCl solution as the low resistive background medium and the vegetable cylinders as the high resistive inhomogeneities. Shallow glass tanks are used as the phantom tank and the tanks are filled with NaCl solution. Sixteen stainless steel electrodes are cut from a 100 µm thick high quality stainless steel sheet (Type 304) and the electrodes are fixed with steel paper clips. All the electrodes are connected with low resistive flexible copper wires using alligator clips and the electrode connection are made with the EIT instrumentation. A number of vegetable cylinders are kept at different electrode positions and a number of phantoms are made for EIT studies. Figure 4 shows a NaCl-carrot phantom with NaCl solution as the background medium and a carrot cylinder near electrode number 3 (E3) as inhomogeneity. The electrical resistivity of the carrot tissues are also measured by the QuadTech 7600 (QuadTech Inc., USA) to compare the reconstructed resistivities with the actual resistivity.

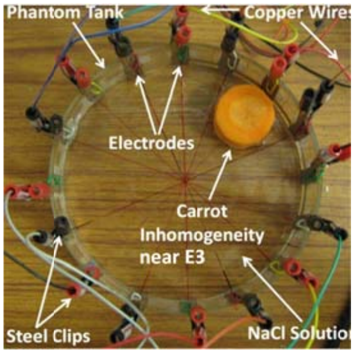

Fig. 4. NaCl-carrot phantom with carrot cylinder near electrode 3 (E3) as the inhomogeneity.

C. Boundary Data Collection

The boundary voltage data are collected from a number of practical phantoms using the battery based EIT system. The Figure 1 shows the 16-electrode battery based EIT system with a patients with surface electrodes attached to its body surface at the plane (cross section of the body) under diagnosis. As shown in the figure, the system generates a constant voltage signal with different frequency points using a multifrequency signal generator and the voltage signal is converted to a constant current signal by a voltage controlled current source (VCCS). The constant current signal is injected to the patient's body at different frequencies through the current electrodes or driving electrodes and the surface potentials are measured at the voltage electrodes or sensing electrodes using the LabVIEW based data acquisition system (DAS). Surface electrodes are switched in a particular switching fashion called current injection pattern or current injection protocol which allows us to conduct the current injection and voltage measurement through using an automatic electrode switching module (A-ESM) developed with analog multiplexers (MUX). 1 mA, 50 kHz constant sinusoidal current is injected to the phantom boundary and the potential data are collected from all the electrode with opposite current injection protocol. In opposite current pattern the current signal is injected through two opposite electrodes (180° apart in space) and the potential data are measured on the other electrodes. In the present study the potential data developed on the domain boundary are collected from all the electrodes. In the sixteen electrode phantoms developed in the present studies, a complete scan provided 256 boundary data though it is observed that only 128 data collected from the first eight current projections are sufficient for image reconstruction. Boundary data are collected are collected from all the phantoms and the data are used for image reconstruction using the image reconstruction algorithm in PC.

D. Resistivity Imaging of Phantoms

The resistivity images are reconstructed from the boundary data collected from all the practical phantoms using Electrical Impedance Tomography and Diffuse Optical Tomography Reconstruction Software (EIDORS) [47-49]. The EIDORS is a Matlab based EIT or DOT (Diffuse Optical Tomography) image reconstruction software which works on the Gauss-Newton approach. In the present study the EIDORS is modified as per the phantom configuration and the forward and inverse problems both are solved with a FEM mesh containing 1968 elements and 1049 nodes. All the image reconstruction processes are conducted with Levenberg-Marquardt Regularization method (LMR) method implemented in EIDORS.

III. Results and Discussion

The Fig. 5 shows the resistivity image reconstructed from the NaCl-carrot phantom shown in the Figure 4 at 12.5 kHz. Experimental results obtained from the electrical impedance spectroscopy conducted by QuadTech 7600 show that the carrot tissue has a resistivity around 160 Ωm. It is observed that the carrot inhomogeneities as well as the NaCl background are properly reconstructed in the resistivity image as the carrot regions are found with higher resistivity values in the reconstructed images. Results show that the resistivity profile of the background and the inhomogeneity matches with the original resistivity profiles of the NaCl and carrot respectively though the carrot resistivity is under estimated.

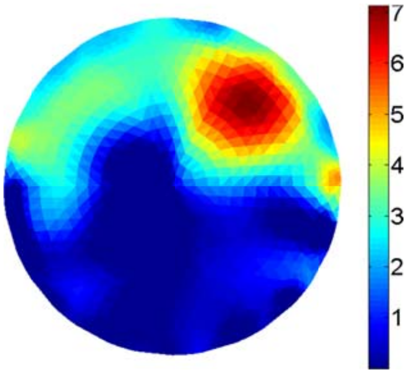

Fig. 5. Resistivity image of the NaCl-carrot phantom (shown in Figure 4) with carrot cylinder near electrode 3 (E3) as the inhomogeneity.

Fig. 5 shows that the reconstructed carrot resistivity is around 7 Ωm at 12.5 kHz which is low compared to the original carrot resistivity. The reason behind the underestimation of carrot cylinder is the large difference between the NaCl conductivity and carrot conductivity. The EIT technology is suitable for the domain containing the materials with low resistivity differences such as the tumor and the normal tissue. But for laboratory studies saline and high resistive materials such as nylon cylinders [3, 8] polypropylene cylinders [6], etc. In the present study the vegetables are used as the high resistive materials to test a battery based multifrequency EIT system as the impedance of the vegetables vary with frequency but nylon or other plastic materials fails to show the frequency depended impedance. The present research study is conducted with different frequencies but due to the results on 12.5 kHz has been presented as per the scope of the paper. The reconstructed resistivity of the carrot tissues is found decreasing with frequencies in multifrequency impedance imaging with the developed battery based EIT system and which correlates with the measured resistivity values obtained by the impedance analyzer. In all the frequencies the carrot tissue are reconstructed with more than the reconstructed NaCl resistivity but decreasing with frequencies. The impedance of the biological tissue decreases with frequencies as the cell membrane of biological cells allow more current to pass through it at higher frequencies [35].

IV. Conclusions

A battery based electrical impedance tomography (EIT) system is developed a battery based regulated power supply (BRPS) for better patient safety in medical imaging. The EIT instrumentation is developed with a constant current injector (CCI), an automatic electrode switching module (ESM) and a LabVIEW based data acquisition system (DAS) and all the instrumentation blocks are fed by BRPS. The battery based EIT instrumentation is studied for constant current inject and boundary data collection in EIT. A number of practical phantoms are developed and the resistivity imaging studies are conducted with battery based EIT system developed. Results show that the vegetable inhomogeneities as well as the NaCl backgrounds are properly reconstructed in the resistivity images. Results also show that the resistivity profiles of the reconstructed phantom domains match with their original resistivity profiles but the vegetable resistivity is under estimated due to the large difference between the vegetable and NaCl resistivity.

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