Development of a Modular 64-Electrodes Electrical Impedance Tomography System

Christos Dimas, Petros Tsampas
Dept. of Electrical and Computer Engineering
National Technical University of Athens
Greece
chdim@central.ntua.gr, ptsampas@yahoo.gr

Nikolaos Ouzounoglou, Paul P. Sotiriadis
Dept. of Electrical and Computer Engineering
National Technical University of Athens
Greece
nikolaos.uzunoglou@gmail.com, pps@ieee.org

Abstract— **The design and implementation of an Electrical Impedance Tomography system with 64 electrodes placed on a 2-D circular pattern is presented. The system's architecture and the algorithm for solving the reverse E/M problem and deriving the conductivity distribution are discussed. Experimental measurements are presented confirming the proper operation.**

Keywords— ***Electrical Impedance Tomography, Finite Elements Method, Phantom Model, Sensor system***

I. Introduction

Electrical Impedance Tomography (EIT) is a medical imaging technique using electrical current instead of radiation or ultrasound waves used in CT (Computed Tomography), PET (Positron Emission Tomography), MRI (Magnetic Resonance Imaging) and other techniques.

EIT was proposed by John G. Webster in 1978 and in 1983 the first visualized EIT system was presented by David C. Barber and Brian H. Brown. Since then a lot of publications have appeared in the literature. By the early 2000s the first experimental EIT systems were introduced by research groups, and by the early 2010s they were used in medical practice. The usage of EIT grows continuously over the time as microelectronic technology and software development is able to increase its capabilities and reduce its drawbacks.

EIT is advantageous due the low cost and portability of the equipment needed. Furthermore, it is safe for frequent use due to the lack of radiation and high temperatures. Current intensity and voltages used are totally safe with no negative health effects[1]. In addition, the measurements can be done fast, in contrast to other imaging techniques, so the examination procedure is in real-time, simple for the doctors and easy for the patients.

Despite those critical advantages, the challenge of EIT is the large number of electrodes needed to generate reliable and clear images of the patient's body conductivity map. Moreover EIT is characterized by much lower resolution in comparison to other imaging techniques. One more challenging thing in EIT is the environmental noise absorbed from the electrodes and the body, which must be reduced using appropriate software and hardware techniques.

In this paper we present the design and operation of a 2D 64-electrodes EIT system with automated computer control.

II. IMPEDANCE MEASUREMENT STRATEGIES

There are many algorithms available to measure the conductivity of patient's tissue using a number N of electrodes. The first and most commonly used one is the *adjacent-electrode* method in which current is applied to a pair of adjacent electrodes and then the resulting boundary potential is measured on other pairs of adjacent electrodes as shown in Fig. 1. This is repeated as many times as the number of the electrodes (N) being used. So a full measurement circle with adjacent algorithm contains N(N-3) differential voltage measurements.

Another widespread strategy is the opposite-electrodes method in which current is applied on a pair of opposite-located electrodes, and voltages are measured from all the other electrodes, with reference to the last electrode before the current input one. Other EIT measurement strategies with much more complexity are the *diagonal one* (or *cross method*), the *conductive-boundary* and the *trigonometric* method.

In this work the adjacent-electrode algorithm is used because it gives more independent measurements than the other algorithms do. It does however generate highly non-uniform current distribution which results in more noisy measurements at the central area [2].

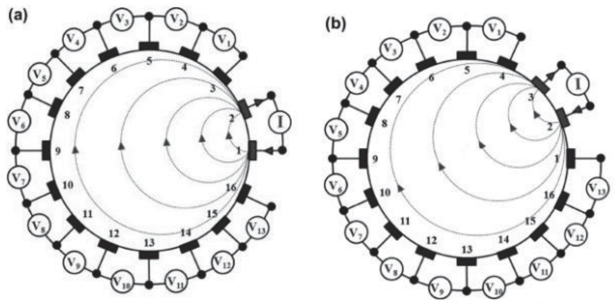


Figure 1: Current patterns of the *adjacent-electrode* algorithm (a) first step (b) second step

III. SYSTEM ARCHITECTURE

To implement the adjacent-electrodes measurement algorithm a differential current source is used. To select the current injection pair and read the voltage output through the rest of electrode pairs, four analog 1-to-64 multiplexers are used. The multiplexers are programmed by a microcontroller board. The differential voltages are fed to a differential amplifier with an adjustable gain and then to the *analog-to-digital* converter of the microcontroller. Finally, the output data is sent to the PC via serial to USB communication.

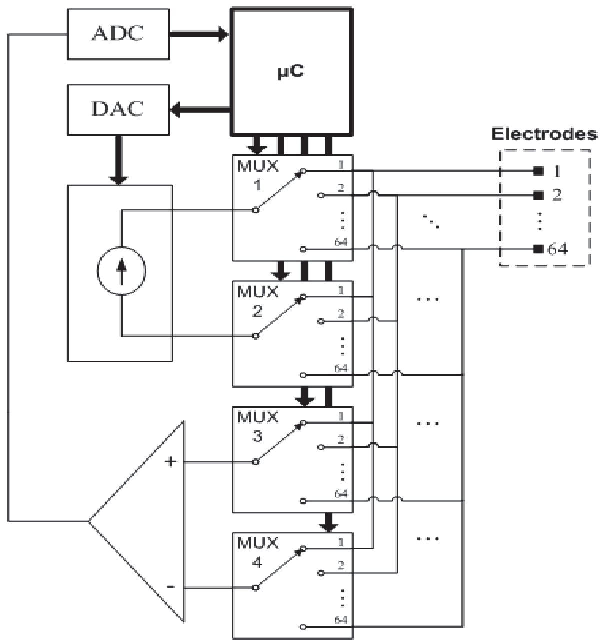


Figure 2: EIT System High-level Architecture

IV. HARDWARE ARCHITECTURE

Biological tissues are characterized by complex impedances; in addition, static electrical potentials due to muscle actions frequently appear randomly. To deal with, sinusoidal (instead of DC) current is used with frequency in the range of 10kHz to 1MHz. Multi-frequency impedance measurements are typically advantageous providing more information. Therefore, the system has to be designed in a way so that it can support a wide range of operating frequencies.

The AC current source is based on a two-stage voltage to current converter. [3] The first stage is based on THS413X, a 150MHz BW differential amplifier, while the second stage uses the quad OpAmp AD8674. A simplified schematic diagram is shown in Fig. 3 (it does not include the common mode feedback network).

Since we use 64 electrodes, four 1-to-64 analog multiplexers are needed. Each one of them is build using four 1-to-16 multiplexers ADG1406 and one 1-to-4 multiplexer ADG1404. Both multiplexers are characterized by very low serial resistance (9.5 and 1.5 Ohms respectively) and practically infinite channel isolation for the frequency range we care. Their total power consumption is about 8.7mA. One other important specification of those multiplexers is the very small switching delay, about 80ns, something which allows taking fast measurements without undesirable delays. Note that a CMOS analog multiplexer can be used both as a multiplexer and a demultiplexer.

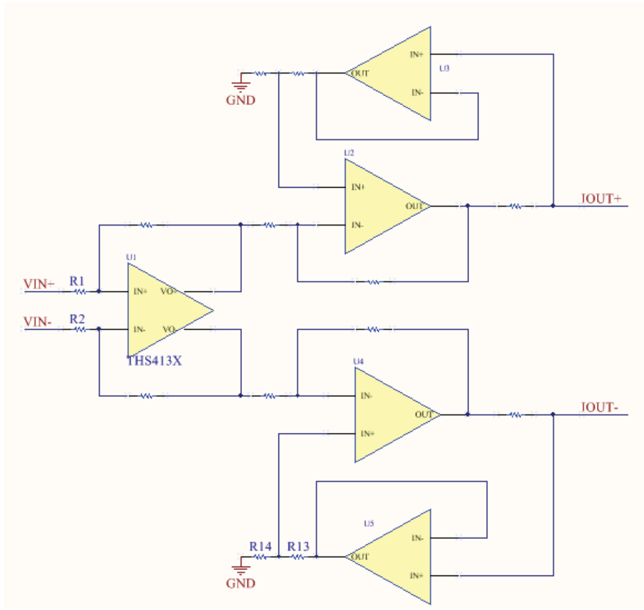


Figure 3: Schematic diagram of the current source circuit

Each 1-to-64 analog multiplexer normally needs 6 bits (control pins) to be programmed, so a total of 24 control pins are required from the μC. To reduce pin requirements, an octal edge triggered D flip flop IC (SN74LV574) with 8 bits and a positive-active clock is used as a buffer before each multiplexer. At every rising clock edge the data passes to the corresponding multiplexer. Thus, we need 6 pins connected with all 4 registers and 4 clocks for each multiplexer's register. Totally, only 10 pins instead of 24 are used resulting in more efficient use of the μC.

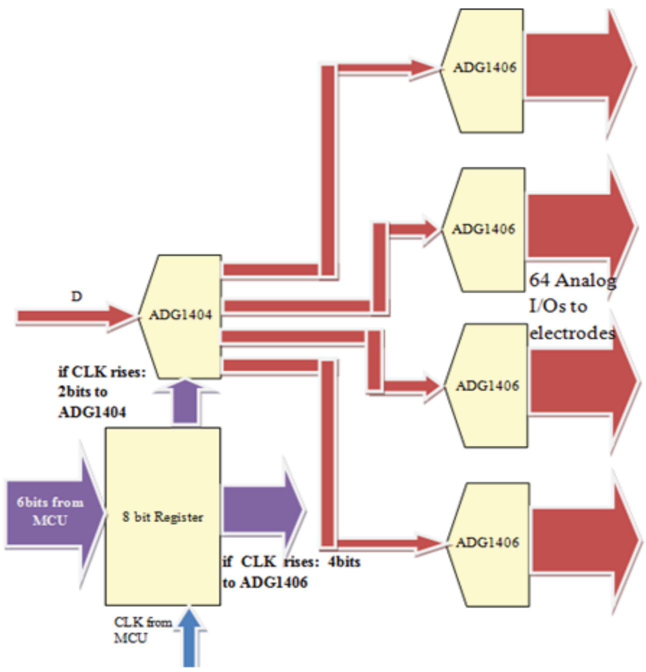
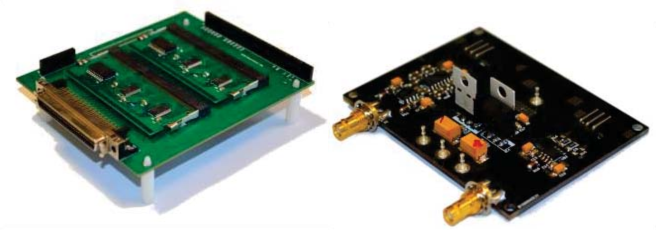


Figure 4: Simplified block diagram of a 1-to-64 multiplexer

Each 1-to-64 multiplexer along with its register is placed on a DDR3-chip type PCB. That type is commonly used for adding ram memories on computer motherboards. All four DDR3 PCBs are locked into the corresponding 4 DIMM connectors on the motherboard. In addition to those, the motherboard also contains a connector for the microcontroller board, a connector for the power supply board and a connector for the electrode cables. The setup is show in Fig. 5a) below.



a) *b)*

Figure 5: a) The motherboard PCB with the SO-DIMM DDR3 multiplexer chips. b) The current source and output instrumentation amplifier PCB.

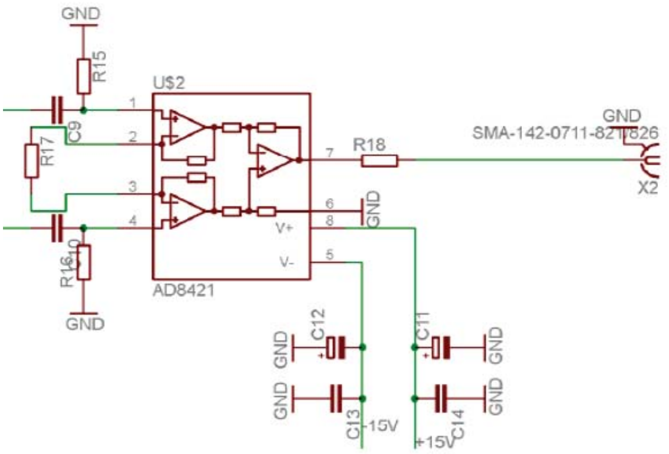


Figure 6: High pass filter & instrumentation amplifier circuit

Generally, biological signals are characterized by high noise levels and so it is important to suppress them be using appropriate filters and common-mode noise rejection via an instrumentation amplifier. Output voltages from two adjacent electrodes are feed, through the multiplexers, to a high pass filter and then to the inputs of the AD8421 instrumentation amplifier (Fig. 6), with adjustable gain, low power consumption (2.3mA max current) and low noise 3.2nV/√Hz.

To program the EIT system and read the output signals an Arduino Due development board is used. It has the ARM μC ATSAM3X8E running at 84MHz, a clock sufficiently fast to operate the system with short measurement cycle. The ADC of ATSAM3X8E has 12 Bits resolution and is programmed in such a way to take up to 1MSs, so the system is able to measure signals with appropriate frequencies for EIT.

One more OpAmp is used to convert the expected voltage range after the filter and instrumentation OpAmp to the 0 - 3.3V range of the ADC and improve the final resolution.

The experimental setup is completed with a 28cm diameter plastic cylinder with 64 metallic screws inserted uniformly on the circumference. The screws are electrically connected to the multiplexer's analog I/Os with a ribbon cable. The total setup with the bottle and electrodes is shown in Fig. 8.

V. FINITE ELEMENTS METHOD FOR SOLVING THE INVERSE PROBLEM IN EIT

The purpose of EIT is to derive the conductivity of the body (phantom) under test by measuring boundary potentials generated by current injection as described in the Introduction. Denoting the conductivity by σ, the voltage φ in the body satisfies the second order linear Partial Differential Equation $\sigma_0\nabla^2\varphi(\mathrm{x},\mathrm{y})+\nabla(\Delta\sigma\nabla\varphi(\mathrm{x},\mathrm{y}))=0$. The boundary conditions are formed of a mixture of measured voltage differences (potentials) and injected current.

The Finite Elements Method (FEM) [4] is employed to solve the boundary problem numerically. It uses segmentation of the body into a finite number of canonical shapes (the elements), e.g. triangles or rectangles in 2D, as shown in Fig. 7 for our case, and tetrahedrons or parallelepipeds in 3D, and approximates the solution inside each element by polynomial interpolation.

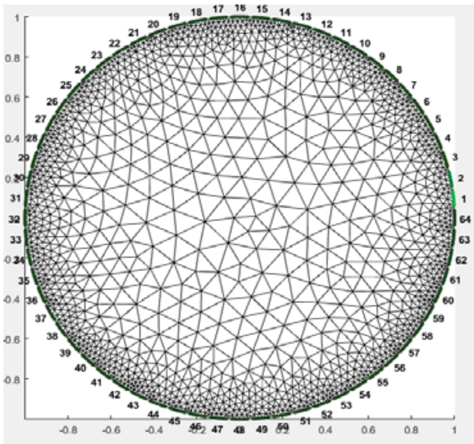


Figure 7: FEM triangle EIT mesh for the discussed 64-electrodes system

For the image reconstruction here, the EIDORS open source function library was used in MATLAB to solve the inverse problem. EIDORS is based on FEM and allows of a variety of geometries and boundary conditions.

VI. MEASUREMENTS AND RESULTS

To demonstrate and test the operation of the EIT system, a phantom was used consisting of the cylindrical setup in Fig. 8 filled with (conductive) salty water. First, the phantom was homogeneous with uniform conductivity to establish a base measurement for calibration and then the uniformity was disturbed by inserting an object of different conductivity and a conductivity image was derived.

In both cases the (same) adjacent-electrodes method, discussed in the introduction, was used, which results in current density higher near the injection electrodes and lower as the distance from the 2 current electrodes increases. Fig. 1 shows the current direction in this case. In every circle a total of 64X61=3904 measurements were taken, i.e., 61 differential voltage measurements took place for every current injecting electrode-pair position. The measured voltages (amplitude) with current input 300μA at 20kHz are shown in Fig. 9, for the homogeneous phantom.

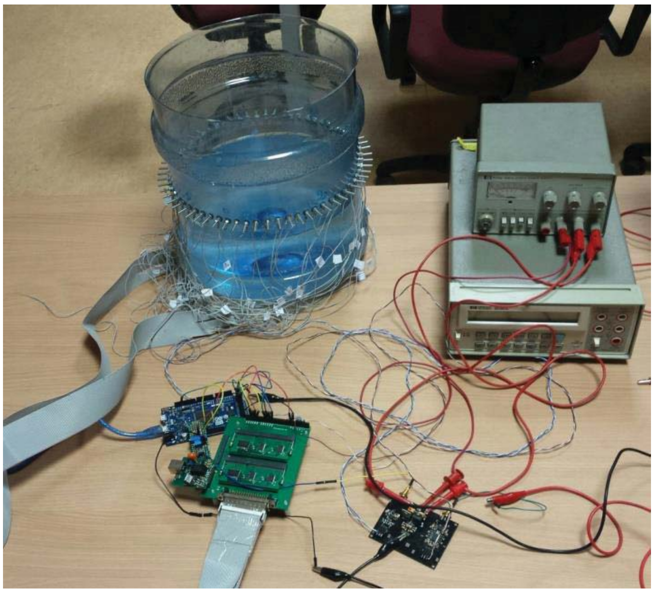


Figure 8: The 64 electrode EIT system setup and its connections.

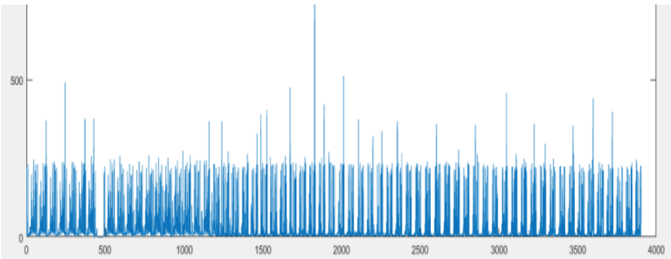
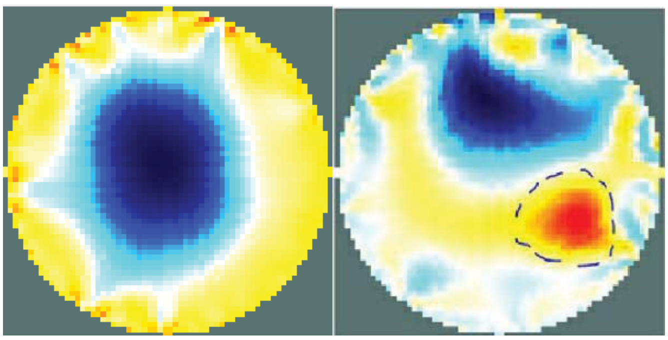
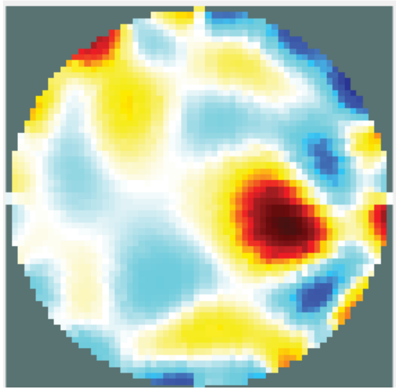


Figure 9: Voltage measurements using the *adjacent-electrode* algorithm from the 64 electrode EIT system in the case of the homogeneous phantom.

Observe the (approximate) periodicity every 61 measurements. A "U" shape is visible, and values (AC amplitudes) turn near zero as the distance from current source increases [5]. Near the current electrodes (every 61 measurements beginning from the 1st one the values are maximized something which verifies the current behavior when adjacent algorithm is used [6], [7]. Fig. 10a shows the conductivity image generated using the homogeneous phantom. For inhomogeneous phantom measurements we inserted a cylindrical glass bottle and measured at 10kHz as well as human hand and measured at 20kHz. The results in these two cased are shown in Figs. 10b and 10c, respectively.



a) b)



c)

Figure 10: a) Homogeneous image b) Image with a bottle inserted c) Image with a human hand inserted. Red color corresponds to lower conductivity.

Two sources of errors have been identified in the experimental setup. One is the position errors of the electrodes in the phantom and the second is the lack of cylindrical symmetry (electrodes are located on a cross-section instead of extending throughout the whole height of the phantom). It is expected that a better phantom would contribute significantly to the improvement of the derived conductance images.

VII. CONCLUSION

Electrical Impedance Tomography despite of its resolution and noise drawbacks is becoming a supplementary biomedical imaging method. This paper presented the design implementation and measurements of an EIT system with 64 electrodes along with an experimental phantom (tank) with the 64 electrodes placed circularly on cross-section. Future work to improve the derived image quality includes the design of a phantom with complete cylindrical symmetry and improvements in the reconstruction algorithms

REFERENCES

[1] Wide -bandwidth, high frame rate electrical impedance tomography spectroscopy. A Code Division Multiplexing (CDM) Approach L. McEwan, D. S. Holde J. Tapson A. van Schaik

[2] Electrical Impedance Tomography (EIT) and Its Medical Applications: A Review R. Harikumar, R. Prabu, S. Raghavan International Journal of Soft Computing and Engineering (IJSCE) ISSN, September 2013.

[3] A Low Cost Electrical Impedance Tomography (EIT) for Pulmonary Disease Modelling and Diagnosis. Venkatratnam Chitturi,Nagi Farrukh, Vinesh Thiruchelvam

[4] Reconstructions of chest phantoms by the D-bar method for Electrical Impedance Tomography, David Isaacson, Jennifer L. Mueller, Jonathan C. Newell, and Samuli Siltanen

[5] Electrical impedance tomography: algorithms and applications Chuan Li Yang, Ph.D. Thesis, University of Bath Department of Electrical and Electronic Engineering, September 2014

[6] Electrical Impedance Tomography: The realisation of regional ventilation monitoring 2nd edition. Eckhard Teschner, Michael Imhoff, Steffen Leonhardt

[7] Switching of A Sixteen Electrode Array for Wireless EIT System Using A RF-Based 8-Bit Digital Data Transmission Technique Tushar Kanti Bera, J. Nagaraju. Department of Instrumentation and Applied Physics, Indian Institute of Science Bangalore – 560012, Karnataka, INDIA.