Performance Evaluation of KHU Mark2 Parallel Multi-frequency EIT System

D Y Kim, H Wi, P J Yoo, T I Oh and E J Woo

Department of Biomedical Engineering, Kyung Hee University, Yongin, Korea

E-mail: ejwoo@khu.ac.kr

Abstract. We describe a new parallel multi-frequency EIT system, KHU Mark2. It is based on the impedance measurement module (IMM), which comprises a single-ended constant current source and a voltmeter. Each IMM has an FPGA for its independent operations including current injection at multiple frequencies, voltage amplification, ADC, digital phase-sensitive demodulation and intra-networking with a main controller of the system. The main controller is based on a DSP and an isolated USB for its connection to a PC. There is an FPGA-based intranet controller, which arbitrates data exchanges between the DSP and multiple IMMs. Unlike its precursor, KHU Mark1, it is a true parallel system with no switching for both current injection and voltage sensing. The small size of the IMM results in a much reduced dimension of a multi-channel system. The KHU Mark2 can be assembled in any channels between 1 and 64. Depending on a chosen application, we custom design an analog backplane that interfaces multiple IMMs with electrodes. Special care was given to the system calibration to maximize its performance in frequency-difference EIT imaging as well as time-difference. Flexibility is the key improvement factor compared with the KHU Mark1. The new system can accommodate any current injection and voltage sensing protocol including the optimal injection current pattern. Reduced size and new internal architecture significantly improved mechanical as well as electrical stability of the system.

Keywords: EIT, IMM, KHU Mark2

1. Introduction

Electrical impedance tomography (EIT) aims to reconstruct image of an admittivity distribution inside the human body [1]. EIT systems measure boundary voltages due to multiple injection currents to reconstruct cross-sectional images of the admittivity distribution. EIT systems have been developed for imaging gastric function, pulmonary ventilation, cardiac function, brain functions and others. EIT is usually used for obtaining time difference images using a time-reference data. When it is impossible to obtain a time-reference data, we may adopt a frequency-difference technique to image acute stroke or cancer for example. EIT systems need a wider bandwidth for better choice of multiple frequencies and multiple parallel channels for faster operations. Depending upon a specific application, it should be able to inject in such a way that we can extract as much internal information as possible. This also requires a flexible electrode configuration.

Our previous EIT system KHU Mark1 has one current source and a switching circuit to inject current between a chosen pair of electrodes sequentially [2-4]. Though it has multiple independent
voltmeters, two inputs of each voltmeter are connected to an adjacent pair of electrodes. In order to overcome these limitations, we developed the KHU Mark2. In this paper, we describe its development and basic performance.

2. Methods

2.1. System structure

The KHU Mark2 EIT system consists of the following parts: (i) a PC with an USB port and EIT software, (ii) a main controller, DSP(TMS320LF2812A, Texas Instruments, USA) with an USB interface, (iii) an intra-network controller on a digital backplane, (iv) impedance measurement modules (IMM) and (v) switching circuits on an analog backplane. Figure 1 shows its structure.

![Figure 1. Structure of the KHU Mark2.](image)

2.2. Impedance measurement module (IMM)

Our previous KHU Mark1 EIT system had one balanced current source and 8 or more voltmeters. The new KHU Mark2 is based on the impedance measurement module (IMM), which includes both a single-ended constant current source and a voltmeter. Using \( N \) IMMs, we construct an \( N \)-channel KHU Mark2 EIT system. Since IMMs are independent each other, the KHU Mark2 can inject current and measure voltage in any possible combinations. Using a high-capacity FPGA (EP3C10F256C8N, Altera, USA), the IMM performs all necessary functions including digital waveform generation, phase-sensitive demodulation, data exchange and controls.

In the KHU Mark1 system, we implemented the balanced current source by two single-ended current sources. The constant current source in the IMM of the KHU Mark2 system is basically identical to the single-ended constant current source in the KHU Mark2 system. The current source is based on the Howland circuit with 4 generalized impedance converters (GIC) [2-5]. We used these GICs at frequencies above 10 kHz to cancel out stray capacitances. Using digital potentiometers (DS1267, Dallas semiconductor, USA), we calibrate each current source for its minimum output impedance of 1 MΩ throughout the chosen bandwidth.

The voltmeter in the IMM consists of the following parts: (i) differential amplifier, (ii) band-pass filter, (iii) voltage amplifier, (iv) ADC and (v) digital phase-sensitive demodulator. Using an ADC (AD9235BRUZ-20, Analog Devices, USA), we fed the voltage data to the FPGA for digital phase-
sensitive demodulations to produce both in-phase and quadrature components.

2.3 Main controller and data communication
The DSP-based main controller controls all functions of multiple IMMs to collect boundary current-voltage data. The sequence of events is as follows: (i) PC sends a command to the main controller, (ii) main controller decodes the command and sends instructions to the intra-network controller, (iii) intra-network controller transmits instructions to IMMs and then (iv) IMM receives the instructions and controls current injection and voltage measurement. Each IMM sends measured data back to PC in the reverse order.

2.4 Table operation
Unlike the KHU Mark1, we implemented table operations in the KHU Mark2, which automate data acquisition and control in a faster way. Instead of receiving one instruction per command packet, we download an instruction table to each IMM including a sequence of multiple instructions such as current amplitude, frequency, voltage gain, GIS settings and so on. First, PC sends a table of instructions to the main controller, which is transferred to the IMM. Second, PC sends ‘Table_Operation_Start’ command. When each IMM receives this command via the main controller, it decodes the table stored in its FPGA. Third, the IMM sets up all hardware settings necessary for the table operation. Finally, when the IMM gets ‘Scan_Start’ command, it sequentially performs all data collection instructions stored in the table.

2.5 Lead switching
The KHU Mark2 is flexible in terms of electrode configuration and data collection protocol. Figure 3 and 4 show two lead switching boards for two- and three-dimensional electrode configurations. Using the analog backplane in figure 3, we can conveniently implement the two-dimensional neighboring method. The analog backplane in figure 4 imposes no predetermined connection for versatile three-dimensional electrode configuration. We may inject current through multiple electrodes at the same time with the same or different frequencies and amplitudes. Voltage measurements between any electrode pairs are possible with this analog backplane.

3. Results
We found that the KHU Mark2 is about 10 times faster than the KHU Mark1 by using the table operation. Figure 5 and 6 show time-difference and frequency-difference images of a saline phantom including an insulator and a conductor anomaly, respectively.
4. Conclusion and Discussion

We developed the new parallel multi-frequency EIT system, KHU Mark2. Using multiple independent IMMs, current injection and voltage measurement can be done in any configuration. We significantly reduced the data acquisition time for a faster frame rate. To reduce the increased power consumption in the KHU Mark2, we plan to develop a SOC for the IMM. Our future studies include thorough performance evaluations and applications to chest and head imaging.

Acknowledgments

This work was supported by the SRC/ERC program (R11-2002-103) of MOST/NRF.

References

[1] D. S. Holder 2005 *Electrical Impedance Tomography: Methods, History and Applications* (IOP: Bristol, UK)
[2] T. I. Oh, E. J. Woo and D. Holder 2007 Multi-frequency EIT system with radially symmetric architecture: *KHU Mark1 Physiol. Meas.* **28**, S183–S196
[3] T. I. Oh, K. H. Lee, S. M. Kim, H. Koo, E. J. Woo and D. Holder 2007 Calibration methods for a multi-channel multi-frequency EIT system *Physiol. Meas.* **28** 1175-1188
[4] T. I. Oh, H. Koo, K. H. Lee, S. M. Kim, J. Lee, S. W. Kim, J. K. Seo and E. J. Woo 2008 Validation of a multi-frequency electrical impedance tomography (mEIT) system KHU Mark1: impedance spectroscopy and time-difference imaging *Physiol. Meas.* **29**, 295-307
[5] A. S. Ross, G. J. Saulnier, J. C. Newell and D. Isaacson 2003 Current source design for electrical impedance tomography *Physiol. Meas.* **24**, 509-516