Electrical Impedance Tomography System for detecting fast physiological signal: KHU Mark2.5

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ABSTRACT

Electrical impedance Tomography (EIT) can produce real-time images of conductivity variations associated with respiratory and cardiac cycles. We report the development of a new multi-frequency EIT system called the KHU Mark2.5. It has new features such as flexible electrode configurations to accommodate application-specific requirements, multiple independent current sources and voltmeters for fully parallel operations, improved data acquisition speeds for faster frame rates due to the pipeline structure and compact mechanical design. Automatic self-calibration is implemented inside a clinical EIT system to improve measurement accuracy and image quality. Developed the EIT system can be cascaded to form a system with a larger number of channels for three-dimensional EIT imaging. We present how we could integrate our EIT system with ECG and respiration monitoring. Integrated system may improve the clinical significance of the patient monitoring.

INTRODUCTION

Electrical impedance tomography (EIT) produces cross-sectional images of a conductivity distribution inside the human body using measured boundary current-voltage data sets. EIT can produce functional images of conductivity variations associated with physiological events such as cardiac and respiratory cycles [1,2]. To correlate such events with EIT images, we may use a biosignal-gated EIT imaging method. Incorporation of ECG and respiration monitoring signals into EIT images can improve interpretation of EIT images [3]. This may allow us to capture fast cardiac events in EIT images and also improve the signal-to-noise ratio (SNR) in EIT measurements.

In this paper, we developed a fully-parallel fast EIT system called by the KHU Mark2.5. We integrated the KHU Mark2.5 system with a custom-developed ECG and respiration monitor using a conductive fabric electrode belt. We will show how to implement fast and cascaded EIT system and its preliminary results for cardiac function and respiration.

METHOD

Figure 1 shows the developed KHU Mark2.5 EIT system and its structure for cascading connection. There are four main parts in a KHU Mark2.5 system as shown in figure 1(b): (i) digital backplane including DSP as the main controller and the FPGA-based intra-network controller, (ii) IMMs including self-calibration circuits, (iii) customizable analog backplane with optional switches for electrode connections and (iv) resister phantom for intra- and inter-
channel voltmeter calibrations\cite{4}. The new IMM used in the KHU Mark2.5 includes a single-ended constant current source, a voltmeter and calibration circuit. Adopting a pipeline structure, it has the maximum data acquisition speed of 100 frames/s with the potential to detect fast physiological changes during respiration and cardiac activity.

A PC controls two independent EIT systems through two USB connections. Before synchronization, they operate independently using their own timing clocks. We first choose one of them as the master and others as slaves. The master controller (DSP) sends a clock synchronization signal through its intra-network controller to other intra-network controllers in the slave systems. It resets the PLL modules implemented in all of the intra-network controllers to synchronize all timing clocks in all EIT systems. Each intra-network controller then sends a trigger signal to all impedance measurement modules (IMMs) inside the corresponding EIT system (either master or slave) so that timings among IMMs are synchronized. After such synchronization steps, the PC may initiate a series of scans by sending the ‘start scan’ command to the intra-network controller of the master EIT system. It then generates a synchronized start-timing signal to the intra-network controllers in all slave EIT systems so that each intra-network controller in each slave system transfers the signal to all IMMs.

![Diagram of EIT system](image)

(a) KHU Mark2.5  
(b) Structure diagram for cascaded EIT system

Figure 1. KHU Mark2.5 EIT system.

We developed an ECG and respiration monitor using a fabric electrode belt as a sensor. The fabric electrode belt includes multiple conductive fabric ECG electrodes and a piezoelectric sensor to measure respiration-related changes of the chest volume. Getting R-wave trigger signals from the ECG monitor, the KHU Mark2.5 initiates a series of EIT data acquisitions with a chosen frame rate. We implemented such timing controls inside the intra-network controller of the KHU Mark2.5 EIT system since it controls all impedance measurement modules (IMMs). Inserting any needed time delay after the gating signal, the intra-network controller broadcasts a series of ‘projection start’ signals to IMMs. During normal and also gated imaging modes, the intra-network controller of the EIT system also generates timing signals of actual EIT data acquisition times. One may use this signal to correlate EIT images with separately acquired biosignals.

**RESULT**

Figure 2(a) shows measured ECG signal. The R-peak trigger signal from the custom-developed ECG monitor initiated a series of EIT measurements. We could average the corresponding images at time points, (c), (d), (e) and (f) in ECG signal \cite{5}. ECG-gated EIT
images were synchronized as ECG signal phase and provided heart functional information from conductivity changes.

(a) ECG signal

(b) Conductivity change in heart region

(c-f) Conductivity images during cardiac cycle

Figure 2. ECG-gated EIT imaging.

Figure 3 shows a series of respiration gating EIT images. Relative resistivity was varied with human respiration. This result shows EIT can produce lung functional images non-invasively. It can be used for clinical application in ICU. We demonstrated how to integrate the KHU Mark2.5 EIT system with a ECG and respiration monitor. The integration will be a valuable feature of the KHU Mark2.5 as a clinical EIT system. Gating signals from the monitor allows us to perform biosignal-gated EIT imaging. Data acquisition timing signals from the KHU Mark2 help us to interpret EIT images together with separately acquired biosignals.

(a) Resistivity change in lung region
(b) Resistivity images during respiration.

Figure 3. Respiration-gated EIT imaging.

With these two functions, we plan to image fast cardiac events as well as slow respiratory events with better SNRs and event synchronizations. We may also apply this integrated system to reject motion artifacts in EIT images [6]. As a part of our future studies, we plan to integrate our EIT system with EEG for multi-modal functional head imaging.

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REFERENCES