System front-end design for concurrent acquisition of electroencephalograms and EIT data

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Abstract.
There is recently considerable interest in medical imaging to combine recording of bioelectrical signals with imaging procedures. For example, electroencephalograms (EEGs) recorded during functional magnetic resonance imaging are increasingly being used for neurological and behavioural research. Concurrent acquisition of EEGs and electrical impedance tomography (EIT) data have been suggested as a non invasive technique that could help localize the area of the brain responsible for seizures in epileptic patients awaiting resective surgery. Despite reasonably distinct spectra, EEGs and EIT signals are difficult to record simultaneously because of their very different amplitudes. In this paper, we describe the front-end of a 24-channel system designed to acquire both signals from the same set of scalp electrodes using time-division multiplexing. We have developed a 10-layer 20x15 cm printed circuit board of the front-end and are currently performing circuit characterization tests. System performance parameters and in vivo images will be presented at the conference.

1. Introduction
Epilepsy is a chronic neurological disorder prevalent in approximately 1% of the general population. Long-term drug therapy is the main form of treatment, but more than 30% of patients are refractory to medication. Patients with uncontrolled seizures require considerable health care resources and experience a high number of disability days leading to unemployment or low income. Surgery is recommended when medication fails and the seizures are confined to an area of the brain where tissue can be safely removed. To localize the epileptogenic zone, patients undergo a pre-surgical evaluation that includes clinical tests, various imaging procedures and video-electroencephalography monitoring. When these tests fail, an invasive study is sometimes performed where intracranial electrodes are implanted under general anaesthesia. Chronic implantation of intracranial electrodes carries a risk of infection and haemorrhage.

Concurrent acquisition of electrical impedance tomography (EIT) data and electroencephalograms (EEGs) have been suggested to assist in the localization of the epileptogenic zone. The rationale for including EIT is the possibility it offers of imaging changes in blood volume and flow that occur during epileptic activity [1]. Identification by both EIT and EEG analyses of an area of the brain with altered hemodynamic and electrophysiological activity, combined to other clinical tests, could reduce the number of cases requiring an intracranial study prior to surgery. Even if an invasive study is done to confirm the results, the EIT-EEG analyses may reduce the number of electrodes implanted and optimize their positioning. The patient would benefit either from elimination of the intracranial study or a reduction of its duration.
2. Methods

The EIT-EEG data acquisition system developed consists of a scan-head, a base-station and a PC. The scan-head (Figure 1, center) contains the front-end circuits for recording EIT signals and EEGs from 24 scalp electrodes. The base-station contains the isolation barrier, data converters, carrier synthesizers and demodulators, acquisition sequencing logic, and a USB-2.0 link. The PC hosts the user interface, displays EEGs and EIT images in real time, and archives the data.

To acquire EEGs and EIT signals with the same electrodes the following time-division approach was adopted. Acquisition intervals of 1 ms are divided in two phases, $T_{EIT}$ and $T_{EEG}$, respectively reserved for EIT and EEG measurements. During $T_{EIT}$, the EIT circuits are enabled and the system performs one transimpedance measurement. Saturation of the EEG amplifiers is prevented by digitally controlled gain stages with very short settling times. When the $T_{EEG}$ phase starts, the EIT current drivers are disabled and the EEG amplifiers returned to their normal (high) gain state. Outputs of the 24 EEG amplifiers are sampled simultaneously and the samples are sequentially digitized by a single A/D converter. Typically, each frame will consist of 250 transimpedance measurements. This leads to an EIT frame rate of 4 Hz and an EEG sampling rate of 1 kHz per channel. Since all timing is controlled by firmware, other operating modes are possible, including acquisition of EIT data only or EEGs only, with corresponding increases in frame or sampling rate.

Figure 2 shows a top-level block diagram of the scan head where the EIT and EEG signal conditioning circuits are abstracted in 24 Active Electrode (AE) modules. The double-ended arrows on the left of each AE module represent connectors for scalp electrodes. Auxiliary Circuits use 4 other electrodes to generate the Wilson Central Terminal (WCT) and the Right Leg Drive (RLD) signals. The System Control bus has 9 lines derived from 4 control signals generated by a sequencer in the base station. The Analogue busses comprise 5 signals. The R signal is the EIT reference carrier which controls the applied current. This carrier is generated by a Direct Digital Synthesizer in the base station. The A+ and A- signals are amplitude modulated carriers originating from the two AE modules selected as the EIT voltage sensing pair. The difference carrier (A+ - A-) is digitized by a 14-bit A/D converter and demodulated by a Digital Down Converter in the base station. The E bus carries the time-multiplexed output samples of the 24 EEG amplifiers. These are digitized by a 16-bit A/D converter in the scan head.
Figure 3 shows the block diagram of one AE module. An instrumentation amplifier (Preamp) amplifies the difference between the electrode potential and WCT. Two microcontroller I/O lines set its gain to 10 V/V during T_{EEG} and 1 V/V during T_{EIT}. The preamp is followed by an EEG high-pass filter (f_c = 0.5 Hz) which rejects the electrode polarization voltage. This filter can be reset by the microcontroller to rapidly restore the signal after an overvoltage condition. The second stage of the EEG amplifier has a digitally controlled gain of 10 V/V during T_{EEG} and 0.1 V/V during T_{EIT}. The settling time of this stage is 500 ns. The third stage combines an instrumentation amplifier and analogue gates to form a sample-and-hold amplifier with a gain of 100 V/V. Data acquisition is initiated by a Control Bus signal which causes simultaneous sampling of all 24 EEG channels. The final stage of the EEG chain is a T-type analogue switch that connects the sample-and-hold output to the E bus.

The EIT signal conditioning chain comprises a current driver (CD) and a wideband preamplifier (WP). The CD consists of a voltage-controlled current source (VCCS) and a 3-way multiplexer. Each CD takes one of three states during the scan sequence: current source, current sink, and open circuit. During T_{EEG}, all current drivers are set to the open circuit state. The first stage of the WP uses the same instrumentation amplifier as the EEG chain. It is followed by a high-pass filter (f_c = 1 kHz) and a multiplexer. WPs take one of three states during the EIT scan sequence: follower, inverter, and open circuit. For the follower state, the multiplexer routes the filter output to the A+ line, whereas it routes it to the A- line for the inverter state. For the open state, the multiplexer disconnects the filter from both lines of the A-bus. These are connected to a wideband differential amplifier and a fast A/D converter in the base station. Since potential differences can be measured between any pair of electrodes and the CDs can apply balanced currents to any pair of electrodes, about 25,000 transimpedance measurements are possible. With N=24 electrodes, N*(N-3)/2 = 252 measurements are linearly independent.
3. Results
The system is under development at the time of writing. Performance parameters of a partially populated printed circuit board of the scan head have been measured with a Network/Spectrum Analyzer. For the EIT signal processing chain, Bode plots of the following parameters were obtained for the 1 kHz to 10 MHz frequency range: a) transconductance, leakage conductance and output impedance of the current drivers and b) voltage gain, crosstalk, common-mode rejection ratio, and intrinsic noise density of the preamplifiers. The signal-to-noise ratio (SNR) and accuracy of the system have been measured with a precision 340-resistor mesh phantom using the test procedure described in [2]. For a 16 channel EIT setup, with 120 cm electrode leads for connecting the scan head to the phantom, we measured a mean SNR of 66.9 dB and a mean accuracy of 98.88 % at a frame rate of 4.7 Hz. Similar tests are under way for the EEG signal processing chain.

4. Discussion
The results of this project will lead to a new method of localizing an epileptogenic zone based on a combination of EIT and video-EEG monitoring. An EIT pilot study on patients with refractory partial epilepsy admitted to the epilepsy unit for a comprehensive pre-surgical evaluation should be able to prove its superiority over ictal SPECT (ascribable to the good temporal resolution of EIT) and show congruency with the reference standard.

5. References
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