Per Pattern-based Calibration Method for EIT Systems

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Abstract: A calibration approach has been developed for use with the EIT systems that are significantly influenced by parasitic impedances associated with switches, multiplexers and channel-to-channel coupling. Calibrated data acquired from saline tank experiments is compared with the data obtained from a forward simulation of the experiment.

1. Introduction

EIT systems often use multiplexers and switches to limit the number of signal sources (current or voltage) in a system. While this approach keeps the electronics simple, it introduces significant parasitic impedances to the system, which must be accounted for during calibration.

Previous approaches have used an inter-channel and intra-channel calibration method [1],[2]. This approach works well for systems that either do not rely on multiplexed signal output or use a differential amplifier based approach to measure voltages. However, in single source, single-ended voltage measurement systems, the higher order effects arising out of channel coupling, and increased current shunting, limits the use of these calibration approaches, in which each channel is calibrated individually. Our proposed approach reduces the influence of these coupling effects on the impedance measurements. Specifically, our approach produces a set of calibration factors for *each* frequency and current pattern applied.

2. Methods

The EIT system [4] is first configured to use as many channels as are required for an experiment (i.e. N=8 channels). A wheel-type resistor phantom [3] with N channel connections on the ring is used during calibration. Circuit simulation software (SIMetrix, UK) is used to obtain the voltage at each node in the calibration phantom for each excitation pattern, i.e., each combination of source and sink channels/nodes. These nodal voltages are stored as calibration reference data.

The phantom is then connected to the EIT system, and voltages at each electrode are recorded for each excitation pattern and frequency. Magnitude and phase calibration factors (CF) for each channel, excitation pattern, and signal frequency are calculated as:

$$CF.Mag(i,pat,freq)\angle CF.Phase(i,pat,freq) = \frac{V(i,pat,freq,sim)}{V(i,pat,freq,exp)} \quad \ldots\ldots\ldots\ldots(1)$$

where the *CF.Mag(i,pat,freq)* is the voltmeter magnitude scaling factor and *CF.Phase(i,pat,freq)* is phase correction factor for channel *i*, excitation pattern *pat*, and frequency *freq*. $V(i,pat,freq,sim)$ represents the simulated complex voltage at channel *i* for pattern *pat* and frequency *freq* and $V(i,pat,freq,exp)$ represents the measured voltage at channel *i* for pattern *pat* and frequency *freq* obtained from a phantom experiment. Let $Mag_{\mathrm{V(i,pat,freq,exp)}}$ and $\phi_{\mathrm{V(i,pat,freq,exp)}}$ represent the magnitude and phase respectively, of $V(i,pat,freq,exp)$. Then, the complex calibration factors can be used to obtain calibrated voltage measurements using:

$$V(i,pat,freq,sim)_{calibrated} = Mag_{\mathrm{V(i,pat,freq,exp)}} \times CF.Mag(i,pat,freq)\angle\left[CF.Phase(i,pat,freq) + \phi_{\mathrm{V(I,pat,freq,exp)}}\right] \quad \ldots\ldots\ldots\ldots\ldots(2)$$

3. Discussion, Results and Conclusion

Calibration data is obtained for each excitation pattern using a resistor phantom with *all* the channels connected to the phantom. This approach is similar to the inter and intra-channel calibration approach, but takes into account the effects of pattern-dependent channel coupling (increased current shunting, higher order parasitic impedance effects), which is often ignored.

To quantify the accuracy of this calibration approach, we collected data in current drive mode using an 8.5cm diameter tank filled with saline solution having a conductivity of 0.1Sm^{-1}. We compared impedances obtained using calibrated data with impedances computed using a forward simulation of the experimental configuration. Our EIT system [4] was configured to measure 1560 tetrapolar impedances from 16 channels. Scaling factors $\left(SCF = \frac{|Z(sim,10kHz)|}{|Z(exp,10kHz)|}\right)$ were computed to quantify the comparison, where *Z(sim)* represents the complex impedance computed using the forward model at 10kHz. The spread of scaling factors defines how well the calibrated data matches the forward simulation. A narrow spread signifies that all calibrated impedances are close to the expected values (based on a forward model). Of the 1560 tetrapolar impedances recorded, 30 (~2%) of the most extreme SCF values were discarded to limit the range of the histogram. The majority of scaling factors are close to 1.1 (Fig. 1). In addition, measurement patterns corresponding to scaling factors distant from 1.1, had small voltage differences (<20 mV) where noise has a more significant impact. In conclusion, this approach can be used for calibrating EIT systems that have moderate parasitic impedances between channels, and potentially helps to account for issues arising out of channel coupling.

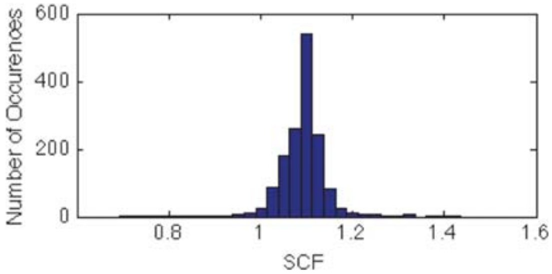

Figure 1: Histogram of SCF with 30 extreme values discarded.

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