

Signal calibration for an electrical impedance mammography system

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Signal calibration for an Electrical Impedance Mammography system

G Sze, N Béqo, N Huber, B Tunstall, R C D Young, C R Chatwin and W Wang
Biomedical Engineering Group, School of Engineering and Design, University of
Sussex, Brighton, BN1 9QT, UK

Email: wei.wang@sussex.ac.uk

Abstract. Electrical Impedance Tomography (EIT) technology has been applied clinically since the 1980s. Numerous papers have addressed a variety of systematic error sources and indicated different calibration methods. The Sussex Mk4 Electrical Impedance Mammography (EIM) system has been developed for the investigation of early stage breast lesions. Investigations have shown that the system performance is subjected to a number of systematic errors: frequencies-dependant noise level due to both internal and external sources; stray capacitance within both PCB tracks and cable connections; and artefacts generated by patient movement during scanning etc. This paper reports upon several traditional and novel calibration methods utilized to reduce some of these errors in the acquired signals before image reconstruction. Techniques used include frequency spectrum analysis, filtering, phase calibration and other means of noise reduction. Results of both before and after calibration are presented and analyzed. The conclusion is reached that the signal quality of the Sussex Mk4 EIM system is such that the system is, post-calibrated, capable of producing images for the diagnosis of breast cancer.

1. Introduction

Signals acquired from an electrical impedance measurement system usually contain noise, systematic errors and interference. These errors, which are caused by internal sources such as ICs thermal noise, stray capacitance and unreliable connections, or external source such as movement artefacts generated from the measurement subject, and EM field interference generated by electronic devices have to be corrected or reduced to a minimum. Most noise sources are constant and their repeatable nature can be easily filtered out with traditional signal processing techniques. However some noise, or interference, is random and requires the use of threshold values applied to filters so that it can be removed. In the worst case the measurement frame may have to be replaced or removed manually after data collection.

1.1 The Sussex Mk4 EIM system

In this paper, signals collected from the Sussex Mk4a EIM system are presented. Noise appearing in these signals can be grouped according to two categories: a) internal noise and b) external interference. In addition to traditional filtering methods we propose using a method that differential the signal with simulated saline signal. Images reconstructed both with and without this method were compared showing that the Sussex Mk4 EIM system is able to produce stable signal of sufficient quality for image reconstruction for diagnosis of breast disease.

The Sussex Mk4 EIM system has been developed for detection of human breast cancer. The system was designed with a planar electrode array used to both inject current and measure the resulting voltage. The data acquisition system (DAS) can generate both the sinusoidal injected signal and

provides digital signals to control the multiplexor for channel switching. Both reference and measurement signals are collected during data acquisition (as shown in figure 1) and are used in a digital demodulation, one is for reference with the other being the transfer impedance related voltage measurement. Magnitude and phase errors are calibrated using the reference signal before processing image. In the ideal case the magnitude and phase changes, between the reference and measured signals, should represent the conductivity changes within the measured volume, but noise from many sources could corrupt the collected signal thus affecting the conductivity calculation.

1.2 Noise

The sources of noise found in the Sussex Mk4 EIM system can be grouped into two types:

1.2.1 Internal noise. Caused by the internal electronic systems, these can be generated by the ICs and any stray capacitance within both PCB tracks and inappropriate cable connections. Most of these sources are repeatable. They could cause frequency dependent DC offset and phase shift within the measured signal and, acting as a low-pass filter, change the magnitude of the received signal at different frequencies. An example of the affected single frequency signal that forced to become a composite signal was shown in figure 1.

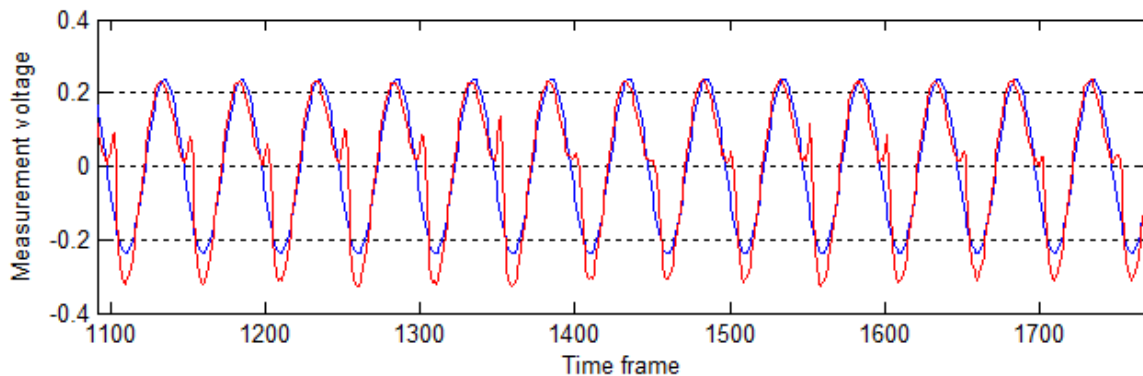


Figure 1. Reference signal in blue and measurement signal in red.

1.2.2 External interference. Caused by all other sources, these are unpredictable and unrepeatable. Typical examples are artefacts caused by patient movement, the effects of nearby X-CT scanning, and mobile telephone signals etc., resulting in sudden changes to the detected impedance magnitude. Most of these external sources are random and therefore more difficult to filter out due to their wide frequency bandwidth.

2. Method

This section lists a number of methods used to calibrate data collected from the Sussex Mk4 EIM system. A calibration method, that differential the signal with simulated saline signal, filters internal noise and is highlighted in section 2.1.2. Images reconstructed both with and without this method were compared using an agar phantom to model the human breast.

2.1 Calibration methods

Firstly collected reference and measurement signal were calibrated using frequency spectrum analysis. We applied Discrete Fourier Transform (DFT) to the measured signal. In the frequency domain, we obtain the magnitude " M_m " and phase " P_m " from the complex value of the applied frequency. We apply the same method to reference signal and get " M_r " and " P_r ". The phase values between " P_m " and " P_r " are subtracted to obtain " P_c ", this aligns phase for every signal generated.

2.1.2 Internal noise. We have “*Mm*” and “*Pc*” from a measurement with object (e.g. human breast), and we need one more set of “*Mm_s*” and “*Pc_s*” from pure saline measurement to calibrate error internally by the system.

“*Pc*” is subtracted by “*Pc_s*” and obtain “*Pc_{sc}*” to calibrate phase, and magnitude is calibrated by a method that differential the signal with simulated saline signal, so except “*Mm*” and “*Mm_s*”, we need to generate a simulated voltage measurement “*Mm_{ss}*”. This method filters the magnitude error, that caused by internal noise, by comparing saline data to the ideal simulated data. It requires the saline data to have a high signal-to-noise ratio [1], and the noise has to be repeatable. The method is implemented by formula $Mm \div Mm_s \times Mm_{ss}$, where “*Mm_{ss}*” is the simulated saline measurement created by solving the forward problem using a uniform conductivity model. Results from an agar phantom are presented in section 3 to investigate the performance of this algorithm.

2.1.3 Unpredictable random noise. Measured frames with spikes and non-responsive measurement channels are removed from the signal following the application of the DFT as shown in figure 2, the measurement frame 500 can be identified as faulty by the application of a DFT extracted voltage threshold that higher than 120. Any faulty frames are replaced or, *in extremis*, removed. The voltage threshold is calculated by the formula $\text{mean}(V_{\text{dft}}) \pm \text{std}(V_{\text{dft}}) \times \text{Factor}$ where V_{dft} is the DFT extracted voltage array and Factor depends upon the acquired signal.

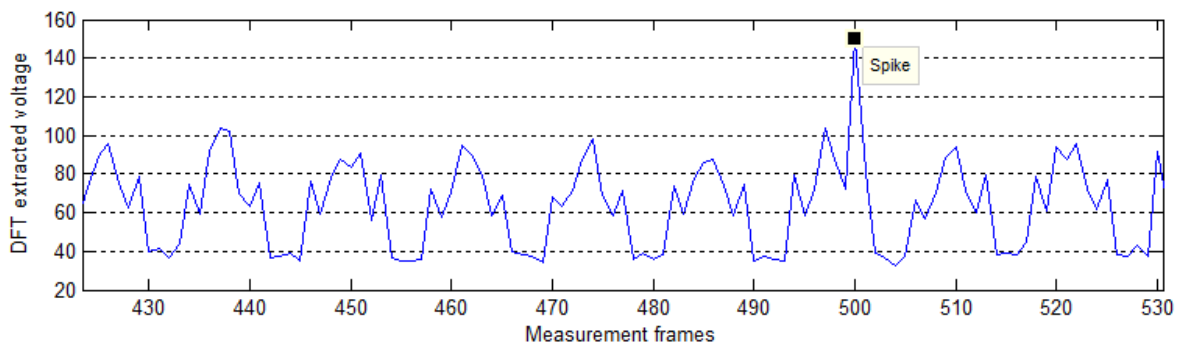


Figure 2. Plotting of DFT extracted voltage signal by measurement frames with spikes.

2.2 Agar model

Data has been collected from an agar breast model set up as in figure 3. It is composed of adipose-simulating material with lowest conductivity 0.43mS/cm shown in black, a stroma analogue with a mid-range conductivity’ and two cancer-mimicking objects (highest conductivity) shown in white, located at 10 o’clock (bigger) and 2 o’clock (smaller) position. The agar phantom was 3cm high so a 3-layers 3D mesh was used to reconstruct image slices with each layer representing a distance of 1cm perpendicular to the electrode array. Note that right layer is touching the electrode plane and is therefore the bottom layer. Saline, with the same conductivity as the adipose-simulating material, was used as a contact medium between the agar phantom and the electrodes.

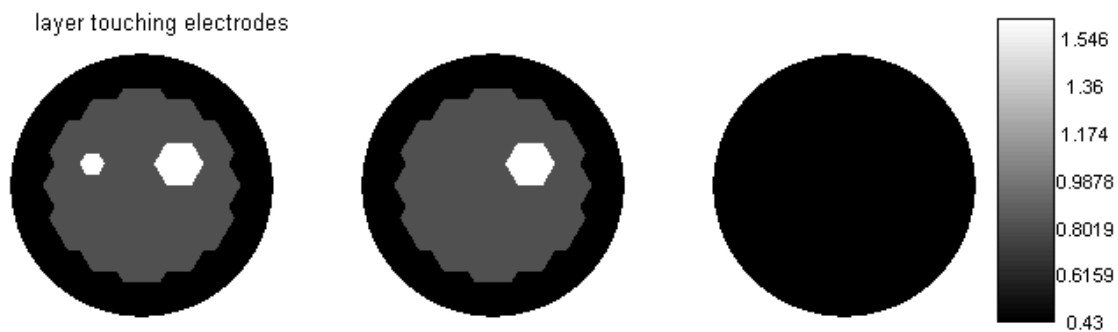


Figure 3. Agar model showing the phantom’s conductivity distribution in mS/cm.

3. Results and analysis

3.1 Results from signal without differentiated with simulated saline signal

- Left layer is dominated by noise, almost obscuring the objects, difficult to distinguish between noise and cancer object.
- Object in the middle layer is not clear.
- Conductivity value is shifted to negative, it doesn't directly related to the true values.

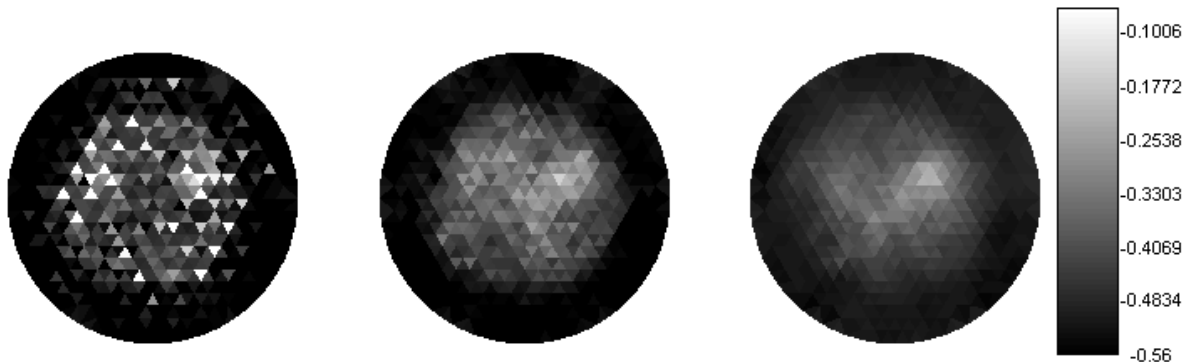


Figure 4. Image reconstructed from signal without differentiated with simulated saline signal.

3.2 Calibration with differential the signal with simulated saline signal

- Noise obviously was reduced.
- Object conductivity is higher than noise, which could be easily extracted from the image.
- Conductivity value is close to the true values.

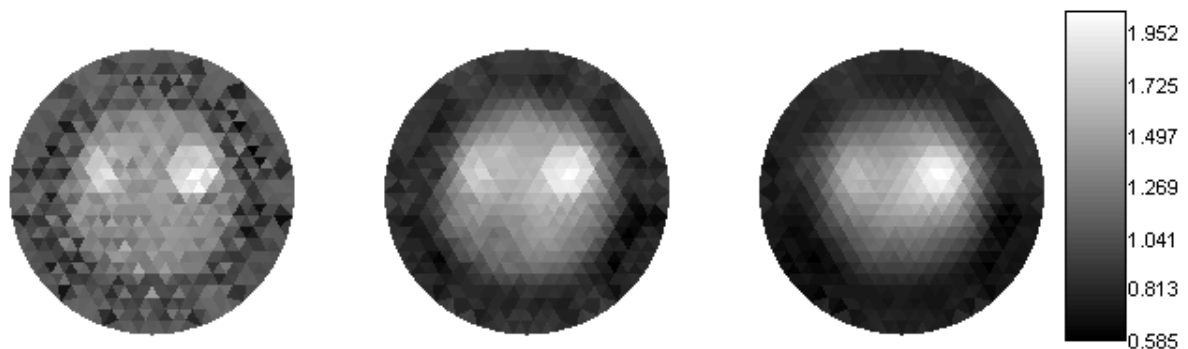


Figure 5. Image reconstructed from signal differentiated with simulated saline signal.

4. Conclusion

This paper presents the calibration of the effects of internal noise and external interference. As can be seen in figures 4 and figure 5, signal differentiated with simulated saline signal is a necessary process to calibrate the data collected. This method for signal calibration is straightforward and essential. Other calibration methods are currently under investigation for further improvement of reconstructed images.

5. Reference

- [1] Wang W, Brown B H, Leathard A D and Lu L 1994 *Physiol. Meas.* **15** A211-A216.