AN ELECTRICAL IMPEDANCE TOMOGRAPHY SYSTEM FOR CURRENT PULSE MEASUREMENTS

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Abstract: In Electrical Impedance Tomography (EIT) measurement sinusoidal currents are applied on a surface of the human body and voltage response is measured in order to reconstruct conductivity distribution in a body cross-section. We have constructed an experimental system for EIT measurement based on voltage response to short current pulses. In this case resistive components of body impedance are measured. Measurements were realized in a vessel filled with water, and conductivity reconstruction was made using back projection method.

Introduction

Electrical impedance tomography is relatively new method for providing body cross-section conductivity images. It is based on the concept that an alternating current passing through an electrically conductive object develops a voltage distribution on its surface. Current pulses are applied to subject using ring of 16 or 32 electrodes, and the resulting potentials on the electrodes are measured. More electrodes would offer better spatial resolution, but it has been found that 16 electrodes is optimal number. Objectively, EIT can be applied for use in pulmonary ventilation, imaging lung water, gastric function or hyperthermia [1].

The EIT systems apply sinusoidal current into the cross-section of the subject. According to patient safety demands, to avoid bio-tissue continuously loaded with current or muscle contraction, applied current amplitude is limited. Both the International Electrotechnical Commission and the American International Standards Institute define the safe current limit for medical equipment to be $100\mu A_{(rms)}$/kHz [2].

In the case in vivo measurement, skin resistance is also critical because the absolute internal body resistance are less then 0.1% the skin resistance and the internal resistance changes are smaller then 1% the absolute internal resistance. Despite this, image reconstruction of internal resistance changes produces better image quality than absolute resistance reconstruction.

Instead of sinusoidal current application, short current pulses with low duty-cycle have been used and voltage responses have been measured [3].

EIT hardware system

EIT system shown in Figure 1 consists of personal computer, PC card, programmable pulse current generator, current switches and voltage module for independent voltage measurements on the electrodes [4]. Current generator generates current pulses with the amplitudes 1, 2, 5 or 10mA, and adjustable frequency and pulse duration (table 1). Time parameters of current generator are controlled through PC card. Duty-cycle should be as low as possible (1:100 or lower), in order to decrease effective current magnitude and increase pulse amplitude. Single current generator is multiplexed between different pairs of electrodes.

Switching module consist of 32 analog switches controlled by digital lines from PC card. PC card has 48 programmable digital input-output lines. The rest of I/O lines is used for controlling current pulse amplitude and voltage multiplexer. Analog switches are independent, so multiply current source or destination can be addressed, according to data collection methods.

The multiplexers and switches are a significant source of error. Input and output capacitances to ground serve to reduce the output impedance of the current source, and the crosstalk capacitance between channels can introduce a significant error signal on a receiving electrode. Used multiplexers and switches (Analog Devices ADG509 and ADG411) have low input and output capacitance (9pF) and low channel-to-channel crosstalk (85 dB).

Eight PC card I/O lines are used for multiplexing a pair of electrodes for voltage measurements. Each electrode pair can be addressed for voltage measurement. Therefore, voltages are measured sequentially, in opposite to systems with multiple S&H circuits, which can measure voltage simultaneously [4]. Measured voltage is sampled and stored in less than 500ns after voltage response rising edge.

Table 1: EIT system parameters

Parameter	Value
Number of electrodes	16
Pulse frequency	1,5-1000 kHz
Pulse duration	0,5-10μs
Pulse magnitude	1,2,5,10 mA
Voltage resolution	12bits
Sampling time	500ns
Input impedance	5MΩ || 5pF

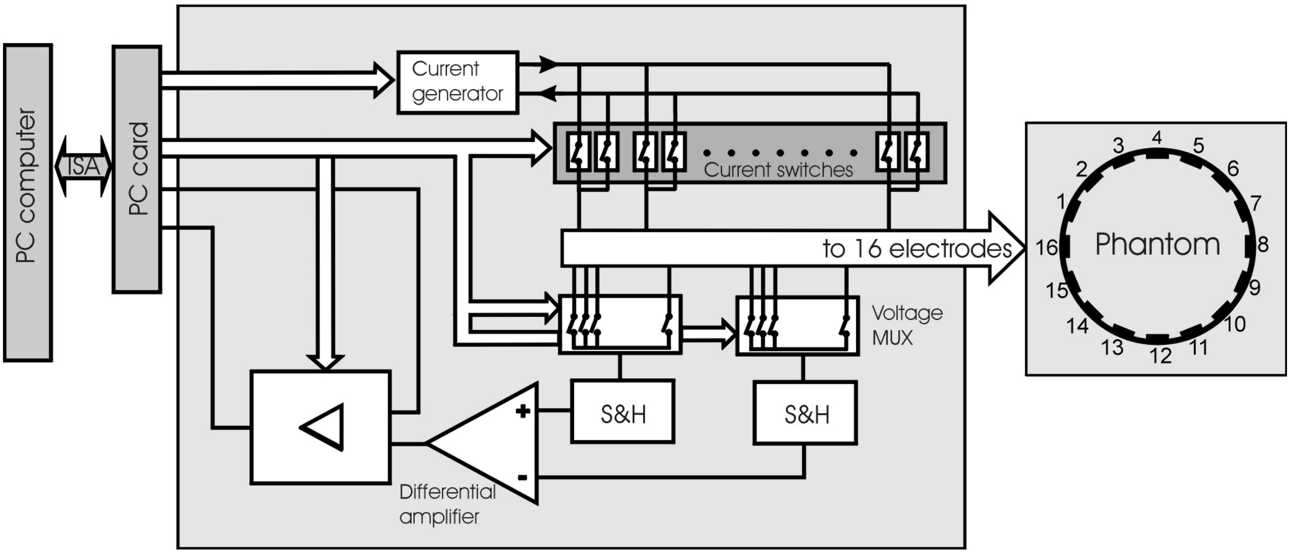

Figure 1. EIT system architecture

To avoid DC voltage offset (constant resistance) at dynamical measurement, PC card built D/A converter is used. After voltage measurement on first pair of electrodes, measured value is stored and after D/A conversion analogically subtracted from all others measured data. In this way differential data voltage resolution is greatly improved.

Described system can addressed every measurement method that does not require multiple current generators or simultaneous voltage measurement.

Measurement method

Measurements have been done using *two electrodes opposite method* [1] with some modifications. Current was injected through diametrically opposite electrodes and voltage was measured on the same electrodes. The voltage reference electrode is addressed to current reference (destination) electrode. One data set (one projections) consists of all diametrically opposed electrodes with parallel current paths, i.e. seven measured data. To obtain the next set of data, current is switched to next pair of opposite electrodes in clockwise direction. The entire image set was obtained by addressing electrodes through 360°. For 16 electrodes, 112 measured data were obtained even some of them were redundant. Measuring algorithm is depicted in Figure 2.

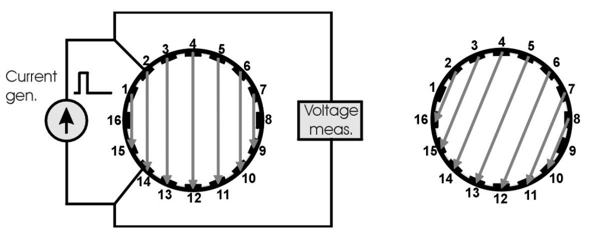

Figure 2.a,b: Measurement algorithm – first and second measurement step

Back projection reconstruction

In image reconstruction there are two mainly approaches. The first consider absolute conductivity image distribution, usually named static image distribution. The second one, used in this paper, is dynamic image reconstruction. That means that data were obtained from object in a particular situation, but conductivity distribution was not calculated. Then, in another situation, second data sets were measured and differential conductivity using the difference of the measured data were reconstructed. Reconstruction has been done using back projection method by back projecting along straight lines i.e. inverse radon transformation instead along equi-potential lines [5].

Measured projection data $g'(r,\theta)$ are stored as 7x16 matrix, where r denotes radial distance of measured electrode pairs from the first electrode, and θ is projection angle. Measured data cannot be used directly to reconstruct the image, due the low spatial resolution. Projection data were interpolated to 50x16 matrix using cubic spline interpolation. In order to reduce non-straight current path errors, interpolated projection $g_{int}(r,\theta)$ should be convoluted with a *sinc* or *triangle* function (1,2).

$$g(r,\theta) = \sum_{j=0}^{n} f_{cor}(r-\frac{D}{2},\theta)g_{\text{int}}(r-j,\theta) \quad (1)$$

$$f_{cor} = \frac{\sin(\pi r)}{\pi r} \quad (2)$$

The inverse Radon transformation is obtained in two steps. In first step, each projection $g(r,\theta)$ is filtered by one-dimensional filter with frequency response $|\xi|$. The result $\hat{g}(r,\theta)$ is then back-projected to yield conductivity distribution $f(x,y)$:

$$\hat{g} \equiv Hg \equiv \int_{-\infty}^{+\infty} |\xi| G(\xi,\theta) e^{j2\pi\xi s} ds = F^{-1}\{|\xi|[Fg]\} \quad (3)$$

$$f(x,y) = BW\hat{g}(s,\theta) = \int_{0}^{\pi} W\hat{g}(x\cos\theta + y\sin\theta, \theta) d\theta \quad (4)$$

where H is a one-dimensional, in this case Sheep-Logan filter, F denote Fourier transformation and W is weight factor for sensitivity correction according to distance from inhomogeneity center to measured electrodes.

Results

Measurement were obtained in cylindrical vessel with diameter D=30cm and 16 1,5x2 stainless steel electrodes located on the wall. Electrolyte was 0,9% saline with resistivity of 50Ωcm. Pulse current with amplitude of 5mA, pulse duration of 3μs and frequency of 5kHz were applied. First measurement was homogenous reference, and the second was done with a piece of wood 2x3cm size in the electrolyte. Obtained data were subtracted to reconstruct difference of resistance. The resulted image with 60x60 pixels resolution is shown in Figure 3.

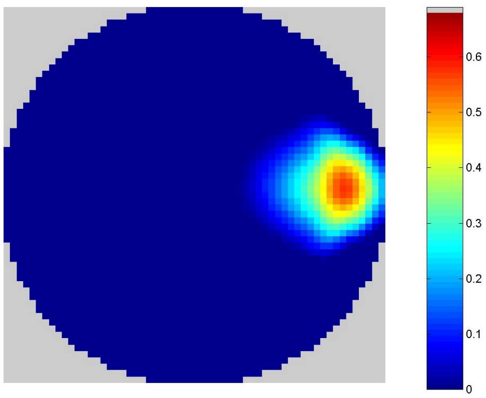

Figure 3: Reconstructed resistance changes distribution

Resistance resolution is up to 0.7% the homogenous medium, which can be increased to 2% with different weight factor W. In both cases sensitivity is higher, more than 50%, in boundary region then in the central as a result of a non-straight current paths. Therefore, different weight factor or different measurement method should be applied in the case of central inhomogeneity.

Conclusion

Described EIT system and measurement method using short current pulses shows that internal resistance can be determined relatively simply without electrode-skin impedance influence. High current magnitude can be used, without risk of bio-tissue overloading. As a result of relatively high voltage amplitudes (several volts) the signal to noise ratio is very high and the input amplifiers gain demands are decreased. The whole system with current pulses is much simpler then sinusoidal current measurements.

The EIT system is inexpensive and portable, and measurements are relatively simple, noninvasive, and non-ionizing. However, image reconstruction methods are more complicated, often with unsatisfied results. Despite of relatively low spatial resolution, incomparable to computed tomography or magnetic resonance there are several possibilities for clinical applications. One of the reasons for further investigation is considerable distinguishing of the electrical characteristics of biological tissue.

Acknowledgment

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