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Passive Electric Impedance Tomography

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Abstract: We introduce an electric impedance tomography modality without any active current injection. By loading the probe electrodes with a time-varying network of impedances, the proposed technique exploits electrical fields existing in the medium due to biological activity or EM interference from the environment or an implantable device. A phantom validation of the technique is presented.

1 Introduction

The aim of the Electrical Impedance Tomography (EIT) is to deduce the spatial distribution of electrical impedance in a region of interest (ROI) enclosed by electrodes. The measurements consist of the potential created on the electrodes as a response to current injection from each electrode, which are expressed concisely as a pairwise impedance matrix. An inverse problem is then solved to infer the properties of the medium [2].

Here we introduce a novel technique for electrical impedance monitoring in which the pairwise impedance matrix of the electrodes is deduced from the voltage response to the loading of electrical fields existing in the medium by means of a time-varying network of impedances switched at a high frequency. The existing fields may result from biological activity (such as EEG, ECG or EMG), power line electrical noise, or from the communication signal of an implantable device. The potential advantages of the proposed passive EIT technique include reduced power consumption due to the absence of active current injection, reduced sensitivity to electromagnetic interferences, decreased nonlinear effects, and the possibility to monitor the bio-impedance change on the frequencies overlaying with the spectrum of the electrophysiological signals while measuring these signals [2, 3]. All these properties are important especially for wearable and implantable devices.

2 Theory and results

We assume a nonzero electrical potential vector $\mathbf{V}_0$ is measured in a conductive medium by means of a passive system of N electrodes characterized by the unknown $N \times N$ pairwise impedance matrix $\mathbf{Z}$ (each z_{ij} measuring the impedance between the electrodes i and j). When the electrodes are loaded by a passive impedance network whose pairwise impedance matrix is $\mathbf{Z}_\mathrm{L}$, the following relation holds between the voltages $\mathbf{V}$ and currents $\mathbf{I}$ on the electrodes

$$\mathbf{V} = \mathbf{Z}_\mathrm{L}\mathbf{I} \qquad \mathbf{V}_0 - \mathbf{V} = \mathbf{ZI} \qquad (1)$$

Given M measurements $\mathbf{V}_i$, i=1,..,N, each corresponding to loading by an invertible matrix $\mathbf{Z}_\mathrm{L}[i]$, the following linear system can be solved for $\mathbf{Z}$

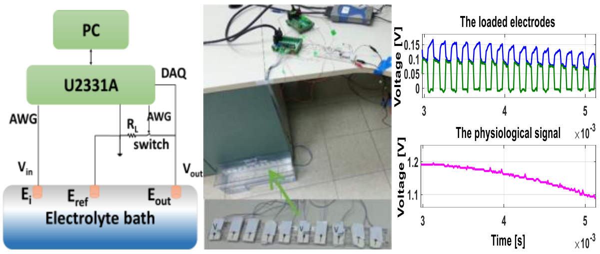

Figure 1: Left-to-right: a schematic diagram of the phantom for the passive EIT, its physical implementation and experimental validation.

$$(\mathbf{V}_0 - \mathbf{V}_1, \dots, \mathbf{V}_0 - \mathbf{V}_M) = \mathbf{Z}\big(\, \mathbf{Z}_{\mathrm{L},}^{-1}[1]\mathbf{V}_i, \dots,\, \mathbf{Z}_\mathrm{L}^{-1}[M]\mathbf{V}_i\big).$$
(2)

The load switching frequency should be fast enough to consider $\mathbf{V}_0$ constant during a single loading period (about 10kHz for the biological signals and in our experimental validation). In such a case $\mathbf{V}_0$ is the voltage measured on the electrodes for the unloaded periods, while $\mathbf{V}_i$ are for the loaded ones. For multi-frequency excitation the values in (1) can be considered phasors [1]. If the signal is much faster than the switching frequency (e.g. communication signal of the implantable device) the values in (1) is voltage power averaged over the switching period (RMS).

Our experimental setup for the validation of the passive EIT technique comprised a saline bath with an immersed electrode array (Fig. 1). The slow "physiological" signal induced in the bath was periodically loaded on the electrodes through the analogue switch by resistors (Fig. 1). Comparing the voltages on electrodes during the loaded and unloaded periods allowed to passively determine the conductivity of the saline solution.

Conclusions

We introduced the theory and experimentally validated a passive EIT technique. In contrast to active EIT, our technique works with low current density on electrodes, which in turn reduces nonlinear effects on the tissue/electrode interfaces and the amount of current injected into tissues, and its power is harvested from the biological activation or noise. The spectrum of potential applications ranges from seizure onset sensing and myocardial ischemia detection to human-machine interfaces.

References

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