Journal of Physics: Conference Series

Optimal configuration of an electrode array for measuring ventricles' contraction

To cite this article: M Lewandowska *et al* 2013 *J. Phys.: Conf. Ser.* **434** 012052

Optimal configuration of an electrode array for measuring ventricles' contraction

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Abstract. An influence of an electrode-array configuration on an impedance signal composition for a fixed spatial distribution of its sources is examined in the paper. The Finite Element Method and Geselowitz relationship were used for examining three different electrode-arrays. A sensitivity approach was used to evaluate each configuration assuming that localization of the signal source is known. A conductivity change, thus the source of the impedance signal was considered as two hemispheres covered by a shell.

1. Introduction

Diagnostics of a heart is a relatively complicated task due to different phenomena involved, i.e. electrical, biochemical, mechanical, etc. Some cardiac diseases manifest in the form of ventricles' dysfunction, for example as a dyssynchrony. This dysfunction, among others, can be manifested as a distortion of the time relationship between the ventricles contractions. Thus, it is very important to have reliable technique which allows examining activity of each cardiac ventricle separately. Potentially, an impedance technique can be used in this application [1]-[3]. It is due to the fact that the impedance technique is also sensitive to a change of examined object's volume. However, an essential problem when using the impedance technique is to separate signal associated with the cardiac ventricles contraction from other ones. Then, the cardiac component of the signal has to be decomposed into two components, each corresponding to the other ventricle. The problem is not trivial as almost all conductivity changes located in the thorax are the consequence of ventricles' contraction. However, it follows from our previous studies that remarkably good results can be obtained when the total impedance signal contains mainly ventricles' components [4]. It can be to some extent, at least theoretically, achieved by using the appropriate electrode-array. Thus, performing at least two-channel measurements and using the appropriate electrode-arrays it should be possible to decompose of the impedance signal into two components arising from different ventricle. The impedance measurement technique is sensitive to conductivity changes undergoing throughout a whole volume of the object to which the electrodes are attached. However, the sensitivity is unevenly distributed in the object. In effect, a contribution of the selected conductivity changes is enhanced in the impedance signal when comparing it to the others. The main aim of the paper is to examine of the spatial properties of the impedance technique for the selected configurations of the electrode-arrays and to choose the optimal one for an anticipated application. It was achieved by means of a Geselowitz's relationship [5] and Finite Element Method (FEM).

2. Method

The change of impedance involved by conductivity variation is described by the relationship proposed by Geselowitz [4]

$$\Delta Z = -\int_V \Delta\sigma(x,y,z)\frac{\nabla\phi(\sigma,x,y,z)}{I_\phi}\cdot\frac{\nabla\psi(\sigma+\Delta\sigma,x,y,z)}{I_\psi}dv, \tag{1}$$

where ϕ represents the potential associated with current I_ϕ flowing between the "current" electrodes, ψ is the potential associated with hypothetical current I_ψ flowing between the "voltage" electrodes after the occurrence of the conductivity change $\Delta\sigma$, V is the volume of the region of changed conductivity, and a dot stands for the scalar product. Basing on this approach the spatial sensitivity is defined as

$$S = \frac{\nabla\phi(\sigma,x,y,z)}{I_\phi}\cdot\frac{\nabla\psi(\sigma+\Delta\sigma,x,y,z)}{I_\psi}. \tag{2}$$

The relationship (2) allows determining the contribution to the total signal, ΔZ, from each subregion assuming that the sensitivity S is known.

The numerical analyses were conducted using FEM and the relationship (2). The analyzed model is presented in figure 1. Cardiac ventricles were simulated as a two hemispheres surrounded by a shell. Two conductivity distributions were considered: homogenous, where $\sigma_1 = \sigma_2 = \sigma_3 = 0.1$ [S/m] and inhomogeneous, where $\sigma_1 = 0.1$ [S/m], $\sigma_2 = 0.22$ [S/m] and $\sigma_3 = 0.5$ [S/m].

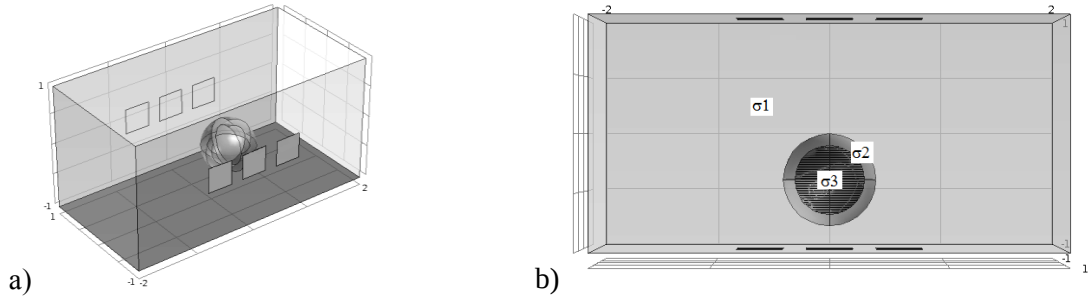

Figure 1. Numerical model of volume conductor a) 3D view, b) top view.

A few different configurations of the electrode-arrays were examined (figure 2). A symmetrical electrode-array for two-channel measurements was composed of current electrodes, I_- - I_+, and two pairs of voltage electrodes $V1_-$, $V1_+$, and $V2_-$, $V2_+$ (figure 2a). In a practical application the distances between electrodes would be different. A localization of the current and voltage electrodes could be the same when using compound electrodes (figure 2b) and the electrode-array (for one-channel measurement) is modelled as a two electrode one. The voltage and current electrodes can interleave and distances between them can also be different (figure 2c).

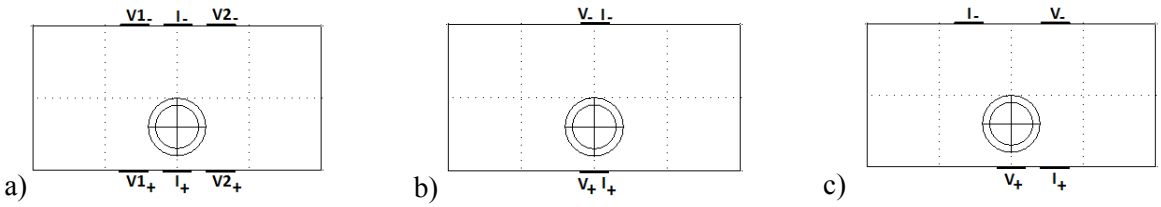

Figure 2. Considered electrodes configurations: a), c) four-electrode impedance technique, b) two-electrode technique.

3. Results

Examples of the obtained sensitivity distributions are respectively shown in the figures 3, 4, 5 and 6. For comparison the sensitivity distributions obtained for uniform objects are also included (figures 3a, 4a, 5a and 6a). Figures 3b and 3c show the sensitivity distributions for different placement of V2+ electrode when a conductivity of the sphere is different from the surrounding one.

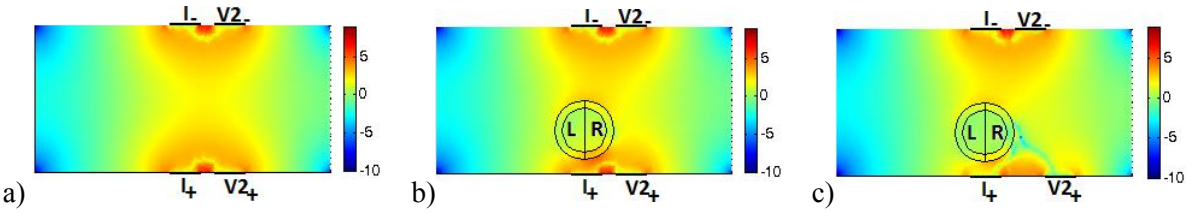

Figure 3. The sensitivity distribution for configuration of the electrode-array given in the figure 2a.

Figures 4b and 4c show the sensitivity distributions for two different positions of the sphere when a conductivity distribution outside the sphere is different and homogeneous.

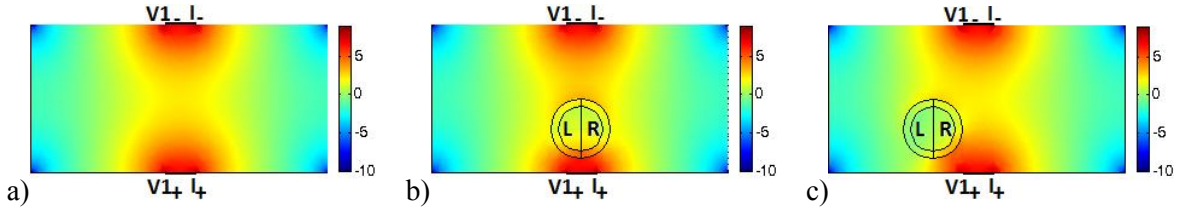

Figure 4. The sensitivity distribution obtained for configuration of electrode-array given in figure 2b.

Figures 5b and 6b show sensitivity distribution for different placement of $V1_+$ electrode for inhomogeneous conductivity distribution when voltage and current electrodes interleave.

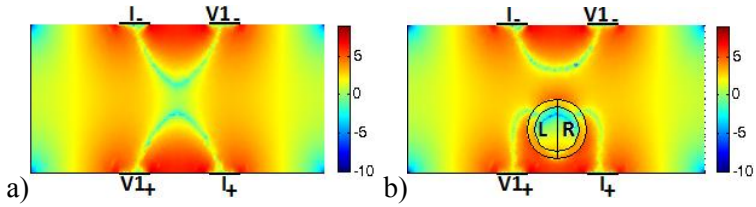

Figure 5. The sensitivity distribution obtained for configuration of electrode-array given in figure 2c.

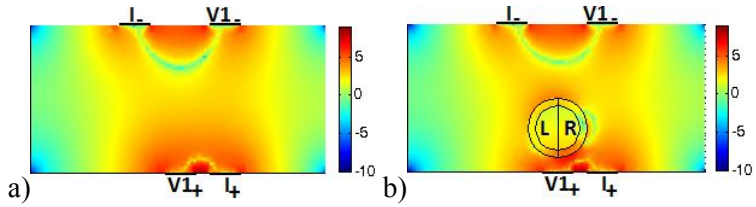

Figure 6. The sensitivity distribution obtained for configuration of electrode-array given in figure 2c.

Table 1 contains the sensitivity assigned to each hemisphere (it was obtained by integration of the sensitivity distribution) related to the total value of the sensitivity (the sensitivity integrated over the whole volume of the model).

Table 1. The relative sensitivity values.

Electrode configuration	Sensitivity for the left hemisphere [%]	Sensitivity for the right hemisphere [%]
2 (figure 3b)	1.000	1.604
3 (figure 4b)	0.727	0.725
4 (figure 4c)	0.093	0.315
5 (figure 5b)	-10.791	-10.798
6 (figure 6b)	2.098	2.516

4. Discussion

The obtained results show that the choice of the electrode-array configuration depends on many factors, e.g. on a goal of performed measurement. It is not possible to create the sensitivity different from zero and located only in desired sub-region. However, it is, to some extent, possible to change relations between contributions (the sensitivity integrated over the sub-region) from different sub-regions. Then, the signal processing methods can be applied to acquire the desired information.

The first examined configuration (figure 2a, figure 3) allows for the best separation of the signals from left and right hemisphere. The obtained sensitivity distribution is relatively uniform. However, it strongly depends on distance between electrodes (figure 3b, c). The main disadvantage of this configuration is relatively low sensitivity compare to the surrounding. It means that if a large conductivity change appears outside the sphere then measurement signal can be heavily disturbed, i.e. the signal from outside of the heart may dominate. The same may appear if a small conductivity change appears in relatively large volume (for example lungs perfusions by blood). In that case time analysis can be used to diminish errors due to such factors.

The second configuration (figure 2b, figure 3c, d) shows that reduction of electrodes number gives large sensitivity near the electrodes. This may cause that measured signal is much smaller and more susceptible to measurement noise. Changing position of the electrodes compare to sphere position changes the influence of left and right hemisphere. The great advantage of such solution is possibility of increasing the influence of the signal from one of the hemispheres.

The configuration from figure 2c is presented to show that there are configurations, which give more powerful signal from the desired region in comparison to other regions, but are not necessary better when other factors are taken into account. The disadvantage of such configuration is the non-uniform sensitivity distribution in the region of interest. This may cause problems in measurement interpretation.

5. Conclusions

The obtained results show that the electrode configuration should be chosen depending on the goal of performed measurement. It is possible to optimize electrode-array configuration in order to obtain a desired property of the sensitivity distribution, e.g. uniformity in prescribed region, or the highest sensitivity in comparison to other sources. Further studies should be performed using more realistic models.

References

[1] Yang F and Patterson R P 2008 A simulation study on the effect of thoracic conductivity inhomogeneities on sensitivity distributions *Ann. Biomed. Eng.* **36 (5)** 762-8

[2] Lewandowska M, Wtorek J, Bujnowski A and Mierzejewski L 2010 Analysis of thoracic regional impedance changes using PCA approach *J. Phys.: Conf. Ser.*, **224** 012162

[3] Wtorek J 2000 Relations between components of impedance cardiogram analyzed by means of finite element model and sensitivity theorem *Ann. Biomed. Eng.* **28** 1352-61

[4] Wtorek J and Poliński A 1995 Examination of impedance cardiography properties-FEM model studies *Biomed. Sci. Instrum.* **31** 77-82

[5] Geselowitz D B 1971 An application of electrocardiographic lead theory to impedance plethysmography *IEEE Trans. Biomed. Eng.* **18** 38-41

Corrigendum: Optimal configuration of an electrode array for measuring ventricles' contraction

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CORRIGENDUM TO: 2013 *J. Phys.: Conf. Ser*. 434 012052

The *References* section should be preceded by *Acknowledgements* section*:*

Acknowledgements
This research was supported by the National Science Centre of Poland grant no. 2011/01/N/ST7/06625