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Separation of respiration and cardiac activity in electrical impedance tomography: Applying harmonic analysis on simulated voltage data

E. Stein[1*], A. Battistel[1], R. Chen[1], and K. Möller[1]

[1] *Institute of Technical Medicine (ITeM), Furtwangen University, Villingen-Schwenningen, Germany*
[*] *Corresponding author, email: e.stein@hs-furtwangen.de*

Abstract: The separation of respiration and cardiac activity in electrical impedance tomography is commonly carried out after image reconstruction. We investigated whether the harmonic analysis approach is capable of separating respiration and cardiac activity based on raw voltage data. In other words, we separated the two signal components before image reconstruction and thus made the separation process independent of it. We created a simple simulation model with two lungs where one only showed respiration and the other one only cardiac activity related conductivity changes. The harmonic analysis approach separated respiration and cardiac activity well when applied on the simulated raw voltages. The mean absolute error and residuals of the reconstructed signal were < 2.5e-3 and < 2e-2, respectively.

I. Introduction

Electrical impedance tomography (EIT) is a medical imaging technology for monitoring respiration on the bedside [1]. Commonly, an electrode belt with up to 32 electrodes is placed around the patient's chest. The electrodes are used in pairs for injecting small alternating currents and for measuring the resulting voltages[1]. The different and changing tissue conductivities in the chest modulate the alternating current. In the reconstruction process the measured voltages are used to create images that displays the different conductivities in the chest [1]. The two main sources of conductivity changes in the chest are linked to respiration and cardiac activity [1]. As the cardiac activity is also present in the lungs, possibly associated with the lung's perfusion, separating these two signal sources in EIT might enable clinicians to directly monitor the ventilation-perfusion ratio (V/Q ratio) [1]. The V/Q ratio is an important indicator of the gas exchange in the lungs.

The separation of respiration and cardiac activity is usually carried out on reconstructed images. However, the chosen separation approach then dependents of the reconstruction process and its modalities. Therefore, carrying out separation on the raw voltages before image reconstruction, e.g. [2], [3], might be beneficial. In addition, 208 voltage channels (16-electrode belt system) are considerably less data to separate than 32 by 32 pixel frames. Following a similar methodology as [3], we investigate whether the harmonic analysis approach [4] is capable of separating respiration and cardiac signals on simulated voltage data.

II. Methods

We built a two dimensional, time dependent finite element method (FEM) model with the EIDORS toolbox [5] in MATLAB 2021b. Battistel et al. [4] provided the code of the harmonic analysis approach.

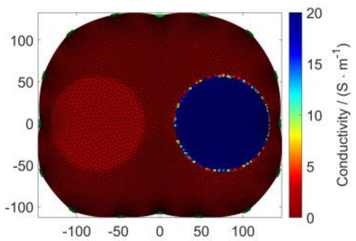

Figure 1: Last frame of time dependent thoracic shaped FEM model, lung with cardiac activity (left) and respiration (right)

II.I. Harmonic analysis

The mathematical details of the harmonic analysis approach have been described in [4]. Previously, we only applied the approach on reconstructed images [4], [6]. Now, we apply it on the raw voltage data. More precisely, we carry out the separation on each of the 208 voltage channels. We fitted ten respiration and ten cardiac harmonics. For the fitting of the respiration and cardiac related harmonics we used two and five coefficients, respectively. The Gaussian window width was set to two. We chose these settings empirically and used them for all 208 voltage channels.

II.II. Simulation

We modeled two lungs of variable conductivity but without volume changes in the FEM model as shown in Figure 1. The conductivity of the left lung was modeled with $\sigma_1(t)$ as in (Eq. 1) and the right one with $\sigma_2(t)$ as in (Eq. 2). We made $\sigma_2(t)$ ten times higher to resemble the commonly reported difference in amplitude of one order of magnitude between respiration and cardiac activity [1].

Also $\sigma_2(t)$ changes at a faster rate than $\sigma_1(t)$ to account for the difference between the heart and respiration rate.

$$\sigma_1(t) = cos\left(2\pi \cdot \frac{70}{60} \cdot t - \pi\right) + 2 \qquad (1)$$

$$\sigma_2(t) = 10 \cdot cos\left(2\pi \cdot \frac{15}{60} \cdot t\right) + 11 \qquad (2)$$

The background conductivity was set to $0.2\ S \cdot m^{-1}$. We simulated a dataset of 1001 frames and used the adjacent pattern for injecting the stimulation current and boundary voltage measurements.

III. Results and Discussion

Figure 2 shows the separated voltages related to respiration and cardiac activity and the corresponding conductivity changes over time. It is clearly visible, that the conductivities and separated voltages are mostly inversely related and share the same frequency. We can also see that the harmonic analysis approach keeps the separated voltages related to respiration at the original voltage level (see Figure 3) while centering the ones related to cardiac activity around zero.

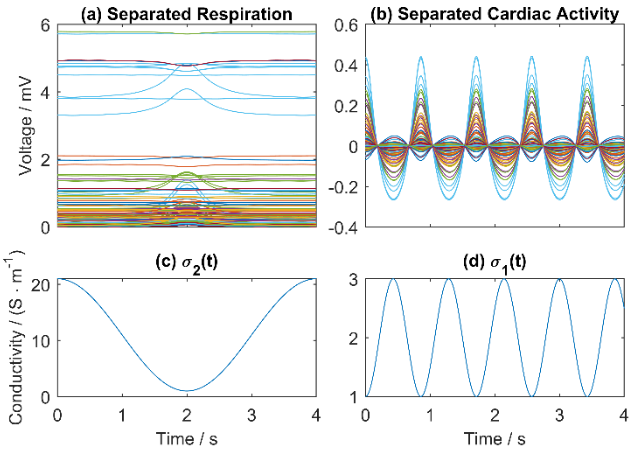

Figure 2: Separated voltages (a), (b) compared to conductivity changes (c), (d)

Figure 3 shows the simulated and reconstructed voltages of all channels. We calculated the reconstructed voltages by adding up the separated voltages related to respiration and cardiac activity. The reconstructed voltage channels look similar to the simulated ones.

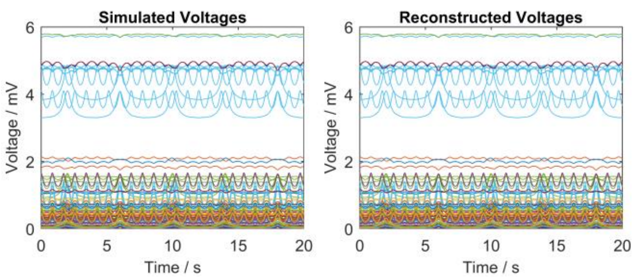

Figure 3: Simulated voltages compared to reconstructed voltages (sum of separated respiration and cardiac activity)

Figure 4 depicts the mean absolute errors (MAE) and the residuals of each voltage channel. We calculated the residuals by subtracting the reconstructed voltages from the simulated ones. Overall, the MAEs and the residuals are about two orders and one order of magnitude respectively smaller than the separated cardiac activity, which we consider to be small errors.

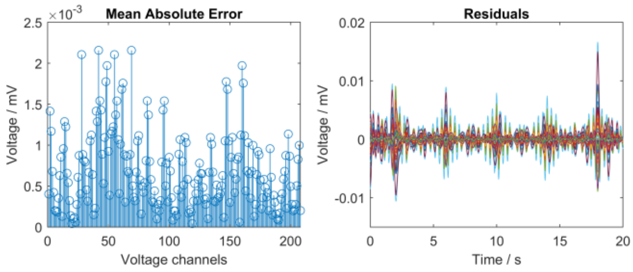

Figure 4: Mean absolute error of each voltage channel (left), residuals of each voltage channel (right)

Having said that, this simulation is a simplification of the human thorax and does not provide information how the approach behaves on real clinical data. Additionally, we did not carry out image reconstruction, which is why we do not know whether the approach is compatible with common reconstruction processes. Nevertheless, we showed that the harmonic analysis approach is not only applicable on pixel values but also on raw voltage data in EIT. These results are in line with other work focusing on the voltage-based separation of respiration and cardiac activity although they used different separation methods like independent component analysis (ICA) [2] or band-pass filtering [3].

IV. Conclusion

In the future, we want to investigate if this approach is also applicable on simulations that are more complicated and check the plausibility of the approach on real clinical data. Additionally, testing the image reconstruction especially on the separated cardiac related voltages might be of interest.

Author's Statement

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References

[1] I. Frerichs *u. a.*, „Chest electrical impedance tomography examination, data analysis, terminology, clinical use and recommendations: consensus statement of the TRanslational EIT developmeNt stuDy group", *Thorax*, Bd. 72, Nr. 1, S. 83–93, Jan. 2017, doi: 10.1136/thoraxjnl-2016-208357.

[2] T. Rahman, M. M. Hasan, A. Farooq, und M. Z. Uddin, „Extraction of cardiac and respiration signals in electrical impedance tomography based on independent component analysis", *J. Electr. Bioimpedance*, Bd. 4, Nr. 1, S. 38–44, Jan. 2013, doi: 10.5617/jeb.553.

[3] T. Zhang, G. Y. Jang, T. I. Oh, K. W. Jeung, H. Wi, und E. J. Woo, „Source Consistency Electrical Impedance Tomography", *SIAM J. Appl. Math.*, Bd. 80, Nr. 1, S. 499–520, Jan. 2020, doi: 10.1137/18M1225264.

[4] A. Battistel, R. Chen, N. Hallemans, R. Pintelon, J. Lataire, und K. Möller, „Harmonic Analysis for the Separation of Perfusion and Respiration in Electrical Impedance Tomography", *IFAC-Pap.*, Bd. 54, Nr. 15, S. 281–286, Jan. 2021, doi: 10.1016/j.ifacol.2021.10.269.

[5] A. Adler und W. R. B. Lionheart, „Uses and abuses of EIDORS: an extensible software base for EIT", *Physiol. Meas.*, Bd. 27, Nr. 5, S. S25–S42, Mai 2006, doi: 10.1088/0967-3334/27/5/S03.

[6] E. Stein, R. Chen, A. Battistel, und K. Moeller, „Separating Respiration and Perfusion in EIT: Harmonic Analysis on 2D-Thorax Simulation", *Curr. Dir. Biomed. Eng.*, Bd. 8, Nr. 2, S. 785–788, Aug. 2022, doi: 10.1515/cdbme-2022-1200.