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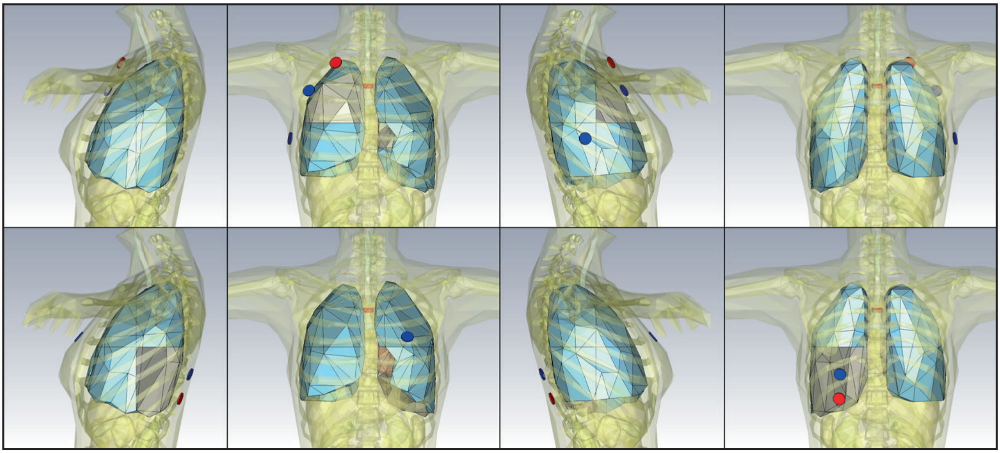
Jakob Orschulik

Monitoring the Respiratory System using Regional Impedance Analysis



Aachener Beiträge zur Medizintechnik

Herausgeber:

Univ.-Prof. Dr.-Ing. Dr. med. Dr. h. c. Steffen Leonhardt
Univ.-Prof. Dr.-Ing. Klaus Radermacher
Univ.-Prof. Dr. med. Dipl.-Ing. Thomas Schmitz-Rode

Monitoring the Respiratory System using Regional Impedance Analysis

Von der Fakultät für Elektrotechnik und Informationstechnik der Rheinisch-Westfälischen Technischen Hochschule Aachen zur Erlangung des akademischen Grades eines Doktors der Ingenieurwissenschaften genehmigte Dissertation

vorgelegt von

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Ein Beitrag aus dem Lehrstuhl für Medizinische Informationstechnik
(Univ.-Prof. Dr.-Ing. Dr. med. Dr. h. c. Steffen Leonhardt).

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Bochum, October 2020

Jakob Orschulik

Abstract

Pathologies of the respiratory system are potentially life-threatening, especially in critically ill patients in the intensive care unit. When not diagnosed and treated in an early stage, they can develop into acute respiratory distress syndrome (ARDS), which is a critical condition with high mortality. Unfortunately, current medical diagnostic methods such as blood gas analysis, radiography, computed tomography, or sonography are not available continuously at the bedside and need to be initiated by a physician. Continuous, non-invasive monitoring, however, would be highly appreciated as it could improve the outcome of the patient.

This thesis investigates the potential of bioimpedance measurement to monitor the respiratory system continuously to detect lung pathologies. In particular, a method named regional impedance analysis (RIA) is introduced, which aims at analyzing the temporal and spectroscopic impedance activity in specified lung regions of interest (ROIs). Based on theoretical considerations, criteria are developed that quantify the ability of specific tetrapolar electrode configurations to focus impedance measurements on specific ROIs. In a complex simulation study, more than 4 million electrode configurations are investigated on their suitability to monitor specific lung regions. As a result, adjusted electrode positions are determined that amplify changes inside the ROI over two orders of magnitude more than changes in the remainder of the lung. From the simulation results, general guidelines on electrode placement are derived that could be transferred easily into clinical practice.

These guidelines are tested by evaluating if pathological changes such as the presence of lung diseases or the lack of ventilation in specific ROIs are detectable in RIA. For this, *ex-vivo* validation studies in simulations and a phantom experiment are performed. The results in both studies confirmed the benefit of adjusted electrode positions. It is shown that changes in the focused ROI have a high impact on the measured impedance, while changes outside the ROI are widely ignored.

Finally, the validity of the concept is further validated in an *in-vivo* animal trial. For this, 17 female pigs are investigated in three groups. In two groups, ARDS is established using different methods, while one group serves as the control group. Temporal and spectroscopic impedance features are extracted and examined in statistical analysis. It is shown that the distributions of extracted features are significantly different between the three groups. Hence, the results of the animal trial indicate that with the right choice of electrode configurations and features, monitoring of the respiratory system using regional impedance analysis is promising.

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