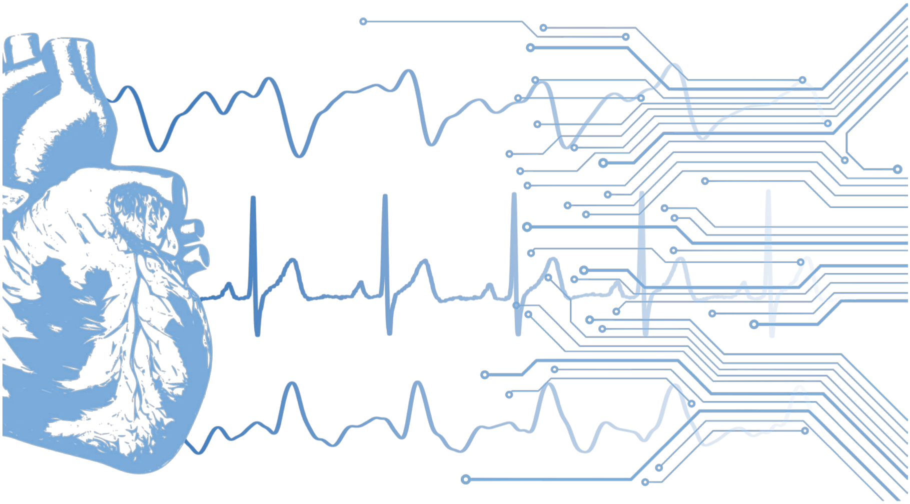
Band 74

Durmuş Umutcan Uğuz

Capacitive Electrocardiography: A Novel Perspective on Motion Artifacts and New Frontiers



Aachener Beiträge zur Medizintechnik

Capacitive Electrocardiography: A Novel Perspective on Motion Artifacts and New Frontiers

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

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Tag der mündlichen Prüfung: 21.04.2023

Aachener Beiträge zur Medizintechnik 74
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

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

RWTH AACHEN UNIVERSITY

Shaker Verlag
Düren 2023

Bibliographic information published by the Deutsche Nationalbibliothek
The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available in the Internet at http://dnb.d-nb.de.

Zugl.: D 82 (Diss. RWTH Aachen University, 2023)

Printed in Germany.

ISBN 978-3-8440-9097-0
ISSN 1866-5349

Shaker Verlag GmbH • Am Langen Graben 15a • 52353 Düren
Phone: 0049/2421/99011-0 • Telefax: 0049/2421/99011-9
Internet: www.shaker.de • e-mail: info@shaker.de

Acknowledgment

These might be the first words in my thesis, yet they are the closing speech of a great time in my life. I know I will be reading these pages whenever I grab my thesis, this souvenir from the Chair for Medical Information Technology.

I want to start by thanking Professor Steffen Leonhardt for being an inspirational and encouraging advisor. He always appreciated my ideas and provided constructive feedback. Moreover, his guidance spanning over these five years provided the framework where I could orientate myself. His presence in our social gatherings and the friendly atmosphere created a sense of family among our colleagues, as the literal translation of his title Doktorvater would suggest. I thank Professor Nikolaus Marx and Professor Omer Inan for their interests in my work and for serving as co-examinors, as well as Professor Michael Vorländer and Professor Johannes Stegmaier for serving on the examination committee.

I have had the luxury of working with two different team leaders: Professor Christoph Hoog Antink and Dr. Markus Lüken. I also want to thank them for being a great support and the first critic of my work. We shared the joy of great results and the frustrations of stepbacks. Another special person deserves mention here. Although I have not worked with him as my team leader, he always managed to be more than that. Our senior scientist Dr. Marian Walter always had an open door for my endless questions, the patience for paying attention, and high spirits to spread to others.

I have had the privilege of working with several students. I want to thank them for making this thesis more valuable: Christian Becker, Can Deniz Bezek, Tugce Canbaz, Berken Utku Demirel, Lucas Keune, Daniel Hirschle, Kai Reymers, Janic Töx, Tuna Berk Tufan, Aydin Uzun, Paul Weidener. I enjoyed our teamwork, and I count myself lucky to be a companion to their theses.

I have a long list of colleagues to acknowledge and keep in my memories. Starting with those who had the curse of sharing their office with me, I want to thank Philip von Platen, Xinchi Yu, Tobias Menden, Simon Lyra, and Florian Voß, in chronological order. I especially thank the last two of them, Simon and Florian, with a slight recency bias for not getting weary of feeding my addiction to hot beverages. Moreover, I want to thank Stephan Dahlmanns and Leonie Korn for pushing and making me a seasonal jogging addict and keeping me company when needed.

I also want to thank Carlos Castelar and Theo Thomas for letting me enjoy being the newbie with their wits; Toni Tholen and Bettina Clever-Offermans, as they have maintained our rushed way of working by keeping things in order against our ever-growing entropy. Furthermore, I want to thank Dr. Boudewijn Venema and Professor Vladimir Blazek, especially for their help in my transition from Master's to Ph.D. at the institute.

I also want to thank my relatively younger colleagues. Due to the COVID-19 pandemic and following turbulent regulations, most interactions have been kept behind cameras, masks, or separate rooms. Nevertheless, we managed to find chances for great conversations and experiences together. In particular, I want to thank Idoia Badiola, Carl-Friedrich Benner, Lukas Bergmann, Patrick Borchers, Jan Kaufmann, Onno Linschmann, Arnhold Lohse, Chenglin Lyu, Cay Rahn, Jöran Rixen, Felix Röhren, Frederich Schwarz, Diogo Silva, Daniel Voss, and Fabian Windeln.

I want to thank Dr. Barış Güleç, Onno Linschmann, Simon Lyra, Jöran Rixen, Uğur Işık Tavukçuoğlu, Dr. Özgecan Uğuz, Florian Voß, and Xinchi Yu for their comments and corrections on my manuscript. I beg the pardon from the readers if I still managed to have typos and mistakes despite the support of these great people.

I am thankful for the support my parents, Meryem and Galip, provided to me, even though they were thousands of kilometers away. Similarly, my late grandmother Cennet Şimşek, who had helped me raise and unfortunately passed away in 2021, will be in my memories from years away. *Her zaman aklımın bir köşesindesiniz.* I want to dedicate my final words to my dear wife Özgecan for her love and encouragement. As much as we enjoy life together, she never steps back from bearing the stress I carry with me. Last but not least, I am grateful for our lovely daughter Lavinia who joined our life last year and brought another level of intensity to this adventure.

Koblenz, April 2023
Durmuş Umutcan Uğuz

Abstract

Unobtrusive measurement techniques allowing cardiac monitoring in out-of-hospital scenarios are expected to play a decisive role in transforming the healthcare system to adapt to changing demographics and more prevalent cardiovascular diseases. Capacitive electrocardiogram (cECG) measurement is among the most prominent candidates that may contribute to large-scale screening to allow physicians to intervene at earlier stages. Using specialized electrode designs, cECG can capture the heart's electrical activity without any preparation, even through subjects' clothing. Although this property has led to various cECG applications like chairs, beds, and car seats in the literature, it also poses the greatest challenge for the cECG technique to become a reliable healthcare monitoring option.

Motion artifacts resulting from the loose contact between the subject and the cECG electrodes have severe adverse effects on the signal quality. Due to high-amplitude motion artifacts, large gaps reduce the availability and robustness of the cECG signal. Moreover, low-amplitude distortions in the signal waveform reduce the diagnostic capabilities and reliability of the cECG. This thesis analyzes the motion artifacts by studying their mechanisms in the electrode-skin interface. The electrode model with time-variant coupling impedance is inspected for the sources influencing the measurement. The thesis proposes the hypothesis that the heart's mechanical activity following the electrical activity can distort the coupling impedance, resulting in motion artifacts correlated with the electrocardiogram.

The thesis then presents a dedicated measurement setup capturing all relevant signals to test the interaction between the cardiomechanical waves, the electrocardiogram, and the time-variant coupling impedance of the cECG measurement. The abstract source-filter model for this particular type of artifact is validated by collecting multimodal data in a study on healthy volunteers. The analyses of the signals made both in frequency and time domains reveal a moderate to strong correlation between the heart's mechanical activity and the distortion in the coupling impedance, leading to a new term: *physiological motion artifacts*. This term coined in this work aims to differentiate from the classical understanding of motion artifacts resulting from independent processes such as limb movement.

Following the core of the thesis, the physiological motion artifacts, the work undertakes a new approach to the time-variant coupling impedance. Instead of inspecting the resulting drawbacks, a novel electrode idea is proposed to utilize the sensitive coupling impedance. This electrode deliberately modulates the coupling impedance at a chosen modulation frequency, resulting in a carrier wave amplitude-modulated with the ECG signal. Therefore, the name modulated ECG is proposed. The first electrode prototype capturing the ECG signal via amplitude modulation is presented starting from analytical solutions on the electrode model, followed by numerical simulations and experimental validation on a physical test bench.

Efforts on understanding and utilizing the sensitive coupling impedance are complemented by a clinical trial aiming to extend the research on the cECG to clinically more relevant subject profiles. This clinical study presents a car seat with cECG electrodes tested on cardiac patients with implanted pacemakers. Multichannel cECG measurement is supported by a fusion scheme and a pacemaker spike detection algorithm, showing that cECG can also capture cardiac pacemaker spikes through subjects' clothing. Limitations are addressed to provide a framework for future cECG applications that aim to cover subjects with cardiac pacemakers.

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