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Eugenijus Kaniusas

Biomedical Signals and Sensors III

Linking Electric Biosignals and Biomedical
Sensors

 Springer

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Preface

This is the *third volume* in my series on “Biomedical Signals and Sensors” developing a bridge between physiology and theranostic human engineering. The *first volume* focuses on the interface between physiological mechanisms and the resultant biosignals that are commonplace in clinical practice. The physiologic mechanisms determining biosignals are described from the cellular level up to the mutual coordination at the organ level. In turn, the *second volume* considers acoustic and optic biosignals with the associated sensors. The formation path of acoustic and optic biosignals is considered on the physiological level, followed by their propagation within the body and coupling into the sensing device. The text follows biosignals on their academic journey from the source to the sensor.

This *third volume* bridges electric biosignals and biomedical sensors from a strategic point of view. The reader learns how electric, magnetic, and electromagnetic fields occur within the body, propagate through and interact with biological tissues, become shaped by homogeneous tissues and boundaries in-between, provoke neuromuscular stimulation and thermal effects, and finally pass the tissue-to-electrode boundary to be recorded. The *biosignal formation path* within the body is described in great depth, followed by the *biosignal sensing path*.

The book series emphasizes the common features of *acoustic*, *optic*, and *electric biosignals*, which are ostensibly entirely different in terms of their physical nature. Heterogeneous signals are discussed within a *common frame* from their formation within biological body up to their sensing by external devices outside the body. While crossing boundaries of different disciplines, such strategic approach mines knowledge of great value.

Electric biosignals and biomedical sensors pose a true *challenge* due to their highly interdisciplinary nature. However, the book helps in managing the challenge while presenting the basics of electrical engineering, physics, chemistry, biology, and physiology that are strategically necessary to understand and work with biosignals and sensors. *Applied basics* are covered at reasonable ease with numerous examples and great attention to detail, as reflected by the large number of footnotes with substantial insights. These academic basics should remain strong because these stand the test of time. It is a rewarding challenge giving the reader the

power to answer intriguing “Aha!” questions and bounding the own advancement to accelerate.

This book is directed primarily at graduate and postgraduate students in biomedical engineering. It is also accessible to those who are interested in physical, engineering, and life sciences, since the expected background knowledge is minimal and many fundamental phenomena are explained. The book should serve engineers and practitioners alike who have an interest in biomedical engineering since all examples are taken from real-world applications and research projects. The book is intended to provide a nice sequel into the effective and in-depth learning as well as into the basic research.

Discussed biosignals and sensing technologies substantiate nascent *wearable technologies*—the hot topic today—which comprise an appealing solution for pervasive monitoring and prompt novel approaches in diagnosis and therapy. These mobile developments have taken giant strides in recent years and truly resonate with the needs of society.

It is important to note that this book was significantly inspired by my *lectures* “Biomedical Sensors and Signals”, “Biomedical Instrumentation”, and “Biophysics” which constitute a significant part of a master’s degree programme “Biomedical Engineering” at the Vienna University of Technology in Austria.

In the end, it is not the spot-like knowledge of diverse biosignals and engineering technologies coming from independent considerations that constitute a successful biomedical engineer with profound professional knowledge, but the *strategic and global expertise* in the genesis of heterogeneous biosignals and of the corresponding sensing technologies.

Vienna, Austria

Eugenijus Kaniusas

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My understanding and appreciation of biomedical issues have been boosted by permanent collaborative research and numerous interdisciplinary studies on national and international level. Years of experience as chairman of the study commission Biomedical Engineering at the Vienna University of Technology (VUT) taught me systematics in biomedicine and cross-topic competence, as reflected by the strategic structure of the present volume despite its profound heterogeneity and interdisciplinary.

This volume of more than 600 pages has claimed extraordinary mental and physical efforts over many years, not only from me but also from my cooperative colleagues and numerous diligent students of mine. I wish to express my sincere thanks and appreciation to Univ. Prof. Adalbert Prechtl from the Institute of Electrodynamics, Microwave and Circuit Engineering (EMCE), VUT, for instructive discussions on electrodynamics and proofreading, and to Dr. Karl Futschik from the EMCE for the support in the field of bioimpedance. I am grateful for numerical modelling of electric fields and careful proofreading by Dipl.-Ing. Stefan Kampusch from the EMCE.

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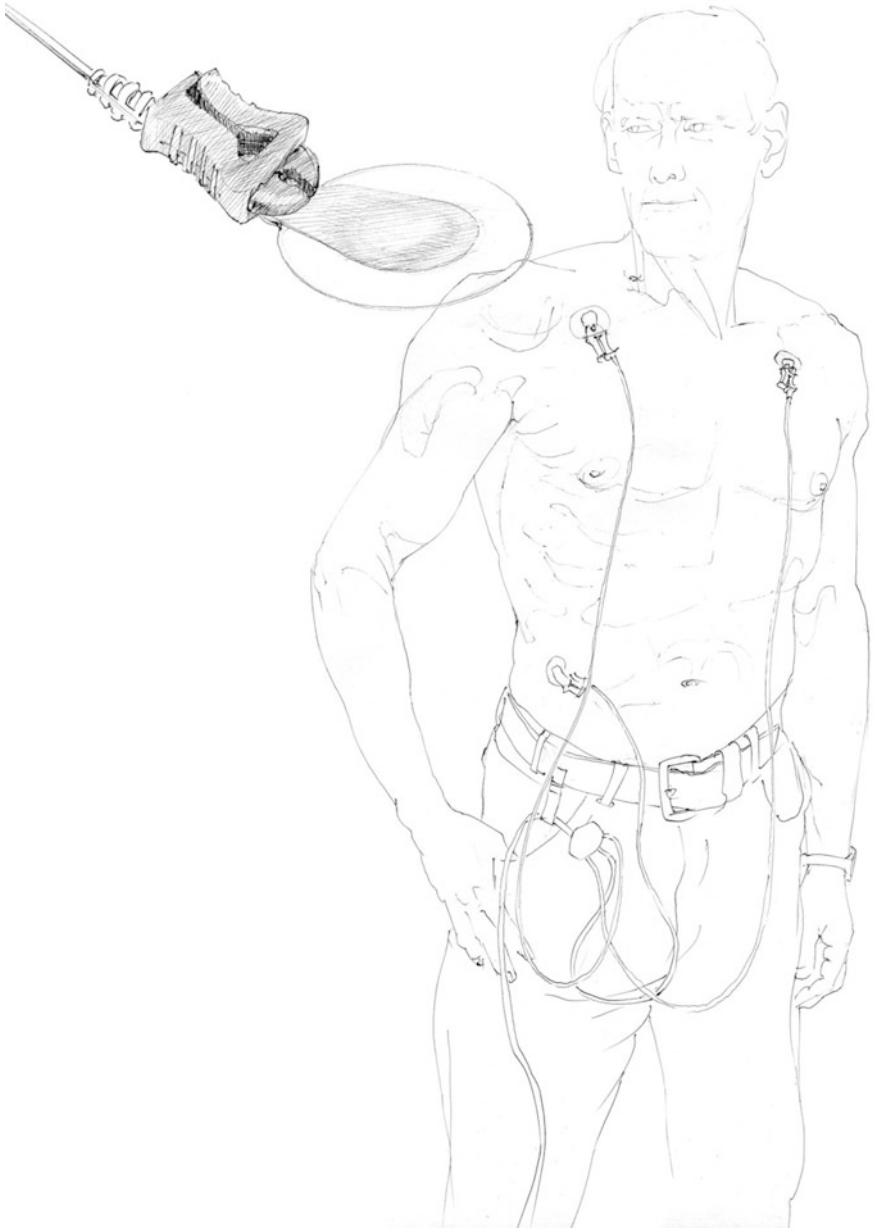
Symbols and Abbreviations

Note Variables used within limited contexts are not listed, for they are described within the relevant section.

a_{Me}	Activity of (metal) ions or species
A	Area
B	Magnetic flux density
c	Constant, specific heat capacity, (molar) concentration
c_{Me}	Concentration of (metal) ions
C	Capacitance
C''	Area-related capacitance
$CMRR$	Common-mode rejection ratio
d	Membrane thickness, distance, size, thickness
D	Axon diameter, electric flux density (electric displacement field)
D_{F}	Diffusion coefficient
e, e	Elementary charge, unit vector
E	Electric field
E_{I}	Incident electric field
E_{R}	Reflected electric field
f	(Oscillating, resonating) frequency
f_{C}	Heart rate
f_{Me}	Activity coefficient of (metal) ions
f_{r}	Relaxation frequency
f_{R}	Respiratory rate
F	Faraday's constant, force
G	Transfer function, electrical conductance
G''	Area-related electrical conductance
HCF	Heart current factor
i	Electric current, index
i_{AC}	Alternating current
i_{C}	(Capacitive) displacement current
i_{DC}	Direct current

i_E	(Electric, ionic) conductive current
I	(Complex) electric current amplitude, intensity of sensation
j_C	(Capacitive) displacement current density
j_E	(Electric, ionic) conductive current density
J	Current density amplitude
J_C	(Capacitive) displacement current density amplitude
J_E	(Electric, ionic) conductive current density amplitude
k	Index, wavenumber, Boltzmann constant
l	length, height, size
L	Inductance
m	Mass, ionic mobility
M	Torque
Me	Metal ion
n	Constant, turns ratio
N_A	Avogadro constant
p	Electric dipole moment
P	Power, electric polarization density field
P_{SAR}	Specific energy absorption rate
Q	Electric charge
r	Radius, distance, (ion) radius
R	Electrical resistance, gas constant
s	Biosignal
S	Substance
S	Power density
SNR	Signal-to-noise ratio
t	Time
T	Absolute temperature, time period
TEM	Transverse electromagnetic wave
u	Electric voltage, object velocity
U	(Complex) voltage amplitude
U_h	Half-cell voltage (or standard reduction potential)
U_{pol}	Polarization voltage
U_R	Resting (membrane) voltage amplitude
v	Electromagnetic wave propagation velocity, nerve conduction (propagation) velocity, drift velocity
V	Volume
W	Energy
x	Coordinate, distance
X	Physical quantity
y	Coordinate
z	Valence, number of electrons
Z	(Complex) electrical impedance, (complex) wave impedance
Z_C	(Complex) capacitive impedance
Z_E	(Complex) conductive impedance
α	Electric field attenuation coefficient, constant

β	Phase angle
δ	Skin depth, Debye length, diffusion layer thickness
Θ	Degree of coverage
Γ	Reflection factor
ε	(Complex) dielectric permittivity, step function
ε_0	Free space permittivity
ε_∞	Dielectric permittivity above the dispersion region
ε'	Real part of complex dielectric permittivity
ε''	Imaginary part of complex dielectric permittivity
ε_r	Relative electric permittivity
ϑ	Temperature
λ	Wavelength
μ	Dynamic viscosity, magnetic permeability
μ_0	Free space permeability
μ_r	Relative magnetic permeability
ρ	Density
τ	Relaxation time constant, time constant
γ	Electrical conductivity
γ_{eff}	Effective electrical conductivity
γ_I	Electrical conductivity of the intracellular medium
φ	Angle, phase angle, electric potential
ω	Angular frequency



D. Chamier, unpublished ball pen drawing, Institute of Art and Design, Vienna University of Technology (2014)