Rajat Emanuel Singh *Editor*

Motion Analysis of Biological Systems

Advanced Theoretical and Computational Concepts

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Dedicated to P. C. Hutchinson
and C. R. Hutchinson.

Dedicated to Mrs. (Right) and Mr. (Left) Hutchinson

Preface

Biomechanics, as a subfield of applied science, focuses on the mechanical analysis of movement. Traditionally, movement analysis relied on Newtonian laws, but recent technological advancements have allowed for the integration of electrical instrumentation to gather biological data. This expansion has moved motion analysis beyond the application of classical physics principles. Presently, numerous studies incorporate advanced concepts and complex data analysis, including chaos theory, nonlinear theory, and other sophisticated approaches, to analyze bioelectrical signals during human motion. As a result, biomechanics has garnered attention from several engineering disciplines, such as mechanical, electrical, computer, artificial intelligence, and biomedical engineering. The inclusion of these interdisciplinary areas, along with appropriate sensor instrumentation, has significantly enhanced our understanding of motion. By detecting subtle changes in movement patterns more accurately, we are better equipped to study human movement and develop solutions to address movement-related issues.

Currently, there is a significant demand for state-of-the-art analysis techniques that can effectively discern differences in movement patterns. However, there is limited literature available that presents advanced theoretical, computational, and technical concepts applied to the motion analysis of biological systems. These advanced concepts and techniques, originating from various applied science areas like biomechanics and engineering, can greatly benefit professionals involved in the rehabilitation of individuals with movement-related disorders. Hence, the purpose of this book is to bridge the gap between these two areas and present advanced concepts and various techniques for the analysis of motion in biological systems.

Orange City, IA, USA — Rajat Emanuel Singh
December 1, 2023

Acknowledgments

This book is not complete without the immense support of the people and organizations that have helped me and uplifted me in different phases of life. From family members to authors and reviewers of the manuscripts. I appreciate their efforts in making this book possible.

First and foremost, I would like to thank Jesus for His wisdom and eternal resources in my life, one of whom was my late grandparents. Therefore, I dedicate this book to my late grandparents, Ms. P.C. Hutchinson, and Mr. C.R. Hutchinson. Ms. P.C. Hutchinson, with the support of her loving husband Mr. C.R. Hutchinson, served most of her life treating the sick, the weak, and the diseased as a nurse in India. She passed away in 2021 due to COVID-19 and deserves much-needed appreciation for her work. This book serves as a tribute to her selflessness and invaluable contributions to healthcare as she rests in Christ.

I would also like to extend my appreciation to my employer, Northwestern College, for providing me with the necessary flexibility and resources to complete this book. Additionally, I am thankful to the authors of the book chapters who put in their effort to provide high-quality articles within the given timeframe (see list of authors). I am equally grateful to the reviewers who diligently evaluated the quality of the manuscript.

A good book is one that effectively conveys its message to the masses, with clarity and conciseness. Therefore, I would like to acknowledge the developers of ChatGPT and Grammarly, the tools that I utilized to check the grammar and flow of the manuscripts. I am deeply grateful to the team at Springer Nature for taking a chance on this book and for their enthusiasm and commitment to its success. From the editorial, design, and marketing teams to their hard work, creativity, and expertise, they have brought this book to life. It is an honor for me to be part of such a talented and dedicated group of professionals.

In conclusion, I would like to express my gratitude to the readers of this book. My sincere hope is that this book fulfills its purpose of providing guidance to professionals in the healthcare industry, ultimately contributing to the betterment of patients.

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About the Editor

Dr. Rajat Emanuel Singh is currently an Assistant Professor of Exercise Science in the Department of Kinesiology at Northwestern College (2021–Present). Prior to joining Northwestern College, he was a postdoctoral researcher at the University of Minnesota, Minneapolis (2021) and at the Joint Department of Biomedical Engineering at North Carolina State University/University of North Carolina at Chapel Hill (2020–2021). He also served as a research intern at the Shirley Ryan AbilityLab of Northwestern University in Chicago (2019).

Dr. Singh completed his master's and doctoral degrees at the University of Arkansas, Little Rock (2015–2019) in biomechanical engineering, specializing in neuromechanics. He holds an undergraduate degree in electronics and communication engineering from Punjab Technical University, India (2008–2012).

Dr. Singh's research focuses on quantifying muscle coordination strategies during the use of assistive technologies for efficient rehabilitation. His published work has appeared in several prominent international journals.

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Acronyms

AC	Activation Coefficient(s)
ADL	Activities of Daily Living
ADT	Adaptation Test
AFD	Analytical Fluid Dynamics
AHP	After Hyperpolarization
ALFF	Amplitude of Low-Frequency Fluctuation
AMT	Adaptive Model Theory
AMTI	Advanced Mechanical Technology, Inc.
AP	Antero-Posterior
APA	Anticipatory Postural Adjustment
APAs	Anticipatory Postural Adjustments
ARDS	Acute Respiratory Distress Syndrome
BDNF	Brain-Derived Neurotrophic Factor
BOS	Base of Support
CFD	Computation Fluid Dynamics
CNS	Central Nervous System
COPD	Chronic Obstructive Pulmonary Disease
cP	Centipoise
CPG	Central Pattern Generator(s)
CSF	Cerebrospinal Fluid
CT	Computed Tomography
Dof	Degrees of Freedom
DS	Double Support
DT	Dual Task
EFD	Experimental Fluid Dynamics
EMG	Electromyography
EP	Equilibrium Point Hypothesis
EPSP	Excitatory Postsynaptic Potentials
ES	Elemental Structure(s)
EVs	Elemental Variables
F	Force

FDI	First Dorsal Interosseous
GAS	Gastrocnemius
HD-EEG	High Density Electroencephalography
HD-EMG	High Density Electromyography
HIIT	High-Interval Intensity Training
ICA	Independent Component Analysis
ICs	Independent Components
IF	Invariant Feature(s)
IFs	Invariant Features
IP	Inorganic Phosphate
L	Length
LOG	Line of Gravity
LV	Left Ventricle
$\bar{x}$	Mean
MC	Motor Control
MCR-ALS	Multivariate Curve Resolution – Alternating Least Squares
MCT	Movement Coordination Test
ML	Medio-Lateral
MMSE	Mini-Mental State Examination
MoCA	Montreal Cognitive Assessment
MOS	Margin of Stability
MP	Motor Program
MRI	Magnetic Resonance Images
MS	Muscle Synergy(s)
MSE	Motor Synergy Encoder
MU	Motor Unit(s)
MUAP	Motor Unit Action Potential(s)
NMDA	N-Methyl-D-Aspartate Iontophoresis
NNMF	Non-Negative Matrix Factorization
OFC	Optimal Feedback Control Models
Pa-S	Pascal-Seconds
PCA	Principal Component Analysis
PCs	Principal Components
PCSA	Physiological Cross-Sectional Area
PD	Parkinson's Disease
PMA-BA6	Premotor Area
Pi	Inorganic Phosphate
PI	Postural Instability
PV	Performance Variable(s)
PVs	Performance Variables
RC	Referent Configuration
ROM	Range of Motion
sEMG	Surface EMG
SMMA	Self-Modeling Mixture Analysis
sNNMF	Sparse Non-Negative Matrix Factorization

SOT	Sensory Organization Test
SS	Single Support
SVD	Singular Value Decomposition
λ	Threshold
TA	Tibialis Anterior
TFA	Transfemoral Amputee(s)
TUG	Time Up and Go Test
UCM	Uncontrolled Manifold Hypothesis
UPDRS	Unified Parkinson's Disease Rating Scale
VAF	Variance Accounted For
Val66Met	Single-Nucleotide Polymorphism Substitution
VE	Virtual Environment
VR	Virtual Reality
XCOM	Extrapolated Center of Mass