Preface

Bioengineering/Biomedical Engineering is currently considered amongst the most reputable fields within the global arena, and has been and will continue to be the primer for any breakthroughs in Medicine and Biology. This field is undergoing an overwhelming global growth so much so that employment indicators show that it is unlikely that it will saturate any time soon. Nowadays, Bioengineering/Biomedical Engineering may be classified into 20 interconnected and at times overlapping key divisions, whereby almost each of these subdivisions could be considered as a field of study in its own right. These divisions include: Bioengineering/Biomedical Engineering Education; Artificial Organs; Assistive Technology and Rehabilitation Engineering; Bioelectromagnetism; Bioethics; Biomaterials; Biomechanics; Biomedical Instrumentation; Biomedical Sensors; Bionanotechnology; Biorobotics; Biotechnology; Clinical Engineering; Medical Informatics and Bioinformatics; Medical and Biological Analysis; Medical Imaging; Neural Engineering; Physiological Systems Modeling, Simulation, and Control; Prosthetic and Orthotic Devices; Tissue Engineering and Regenerative Medicine. Nonetheless, due to the leaping advancements in technology, the field of Bioengineering/Biomedical Engineering is continuously changing, and there is no doubt that new areas in this field are to be introduced to the aforementioned well-established divisions.

The Handbook of Research on Biomedical Engineering Education & Advanced Bioengineering Learning: Interdisciplinary Concepts is a highly specialized, peer reviewed, comprehensive, and contemporary handbook, written by a panel of international experts and giants in the acclaimed field of Bioengineering/Biomedical Engineering. This handbook is very much needed and desired in both academic and research domains around the world, specifically in developing and transitional countries where this field is flourishing nowadays. Its main benefit is twofold: The first being its potential usefulness in research and development (R&D) for research scientists and practitioners in Bioengineering/Biomedical Engineering; such as, bioengineers, biomedical engineers, practicing clinical engineers, and electrical and mechanical engineers working within the field of Bioengineering/Biomedical Engineering. It also has a potential for use by other closely related entities, such as industry, accreditation agencies, professional societies, academic institutions of higher education, ministries of higher education, and other governmental agencies. The other benefit is its suitability as a reference for advanced bioengineering/biomedical engineering courses, as well as broader courses in engineering, life science, and medicine. Moreover, a student who has the appropriate math/physics/chemistry background may find this handbook a useful gateway into the Bioengineering/Biomedical Engineering major. It could be used, as well, as a supplementary reference in undergraduate/graduate programs offering Bioengineering/Biomedical Engineering around the world. Furthermore, it could be used by post-doctoral fellows pursuing R&D in specific areas of Bioengineering/Biomedical Engineering.
The handbook is comprised of 18 chapters arranged in two volumes addressing, in both breadth and depth, all subdivisions of the field except for Biotechnology and Tissue Engineering and Regenerative Medicine. Each chapter is written by one or more authority in the pertinent key division. Future editions of this handbook will include chapters on Biotechnology and on Tissue Engineering and Regenerative Medicine, as well as on any new emerging subdivision in this field. Moreover, much of the physiology has been omitted purposefully to keep the book focused and within a reasonable size. In this context, the interested reader is directed to three excellent works, namely: Marieb E.N. & Hoehn K. (2010), Human Anatomy & Physiology, Eighth Edition, San Francisco, CA, USA: Benjamin Cummings – Pearson Education; Koeppen B.N. & Stanton B.A. (2008), Berne & Levy Physiology, Sixth Edition, Philadelphia, PA, USA: Mosby – Elsevier, Inc.; and, Guyton A.C. & Hall J.E. (2006), Textbook of Medical Physiology, Eleventh Edition, Philadelphia, PA, USA: Elsevier – Saunders.

As for the structure of this handbook, it has been carefully considered in order to make the book unique in its category. The handbook is concise, consistent, homogeneous, well-illustrated, applied, and all-inclusive. It delves into both aspects of bioengineering/biomedical engineering, namely theoretical and applied. It identifies methodologies, concepts, tools, and applications through reference citations, literature reviews, and quantitative and qualitative discussions. In addition, the handbook includes real-life computational, design, and research-oriented worked out examples, models, simulations, et cetera. Every chapter begins with a definition of the pertinent subdivision and concludes with a speculation about the future of this subdivision, to end with an identification of related professional societies and organizations. Furthermore, the reader should be capable of assimilating what is to be gained from each chapter right upfront through a list of objectives.

Chapter 1, by Abu-Faraj, presents a comprehensive analysis of Bioengineering/Biomedical Engineering Education. It begins with a formal definition and an in-depth overview of the evolution of bioengineering/biomedical engineering education supported by a thorough body of literature. This is subsequently followed by a detailed description of state-of-the-art curriculum philosophies, an insight into existing academic curricula, and recommendations about career development. The chapter ends with an analytical comprehensive study on the world promulgation of bioengineering/biomedical engineering education with a forecast of the future of bioengineering/biomedical engineering education.

Chapter 2, by Catapano and Verkerke, presents an in-depth analytical view of Artificial Organs. It emphasizes design as a cornerstone of the education of future professionals and scientists, whose high-level of specialization is required to develop prospective innovative artificial organs that will replace or support missing or malfunctioning human organs and tissues. A major body of recommendations is given to related academic programs, discussing possible improvements to the way courses on artificial organs design are offered so as to make them better adapt to the rapid evolution of the methods employed in the design of artificial organs, and to the needs of healthcare systems.

Chapter 3, by Szeto, provides a detailed overview of Assistive Technology and Rehabilitation Engineering, with emphasis on the areas of current interest, recent successes, and future promises. It addresses the principles of assistive technology assessment, rehabilitation engineering, ergonomics, and product design, as well as the technical issues that an assistive device must overcome for several major categories of disabilities. Within this context, some of the main physical and psychological consequences of different disabling conditions are presented together with the technical challenges that such disabilities create. The chapter also covers some of the practical aspects such as the employment outlook for this field, the training and educational programs that are available, and the professional societies and organizations related to this field.
Chapter 4, by Wood, presents a survey of the emerging discipline of Bioelectromagnetism with its three overlapping, though somewhat distinct, areas: Bioelectricity; Biomagnetism, and Bioelectromagnetics. The first two are strongly allied with diagnostic techniques in clinical medicine, but the third has extremely important implications in sociology and public policy. The chapter explores the aforementioned aspects, along with the basic engineering principles underlying their biological effects. It also presents some of the present challenges and future prospects of the said discipline, and a detailed understanding of the way electric and magnetic fields interact with biological tissue to ensure that the beneficial effects are optimised and the risk of harmful effects are minimized, through appropriate guidelines. The chapter also sheds light on a number of promising new emerging prospects, which may represent significant advances in medical diagnosis or therapy and in biotechnology.

Chapter 5, by Monzon, presents the historical evolution of Bioethics and describes the main moral concepts that have characterized human conduct in different places along history. It discusses the terrain of bioethics, namely metaethics, normative ethics, applied ethics, and descriptive ethics. Then, addressing the moral dilemmas as consequences of the evolution of medicine, the chapter indicates how the merging of the ethical issues of curative medicine and the civic ethics of preventive medicine generates the wider concept of Bioethics. The chapter highlights the accepted principles of biomedical ethics of autonomy, beneficence, nonmaleficence, and justice. It also presents the codes of ethics as a synthesis of the responsibilities of the medical and engineering professions. It then draws attention to the importance of introducing bioethics in biomedical engineering education. The chapter ends with a brief commentary on the future of Bioethics and the presentation of a list of societies and organizations related to this field.

Chapter 6, by Chu and Wu, addresses Biomaterials as an interdisciplinary science, bringing together various different fields in medicine, biology, mechanics, and surface engineering. It is involved in the development of modern medical therapies and tissue engineering as well as human health – from biomedical devices, to diagnostics, to drug-delivery systems. As such, the chapter reviews the general development of Biomaterials including: biocompatibility, evolution, traditional classifications and properties, interactions with cells, surface modification, as well as typical applications. The chapter also touches on the possible future trends in biomaterials R&D and ends with a listing of pertinent professional societies and organization.

Chapter 7, by Slavens and Harris, presents a broad overview of Biomechanics and several of its subdisciplines. The chapter begins with the basic principles of Biomechanics, to be followed by a description of the biomechanics of tissues in the musculoskeletal system as well as that of joints. It then focuses on applied biomechanics from postural stability, to movement analysis, to sports biomechanics. Subsequently, a delineation of modeling methodologies for the musculoskeletal system is presented using finite element analysis and other software packages. Moving to clinical biomechanics, the chapter highlights the importance of biomechanics when studying assistive mobility devices and postural stability for people with different pathologies. The chapter then gives insight to human limits and tolerance for injury through the study of head, neck, chest, and abdomen trauma biomechanics. Moreover, safety in the workplace is discussed as an important aspect in the area of occupational biomechanics. The chapter ends with an identification of professional societies and organizations that are active within this field.

Chapter 8, by Webster, addresses Biomedical Instrumentation with a focus on the measurement of biopotentials and their use in diagnostic applications. Biopotentials include: the electrocardiogram (ECG), the electroencephalogram (EEG), the electrocorticogram (ECoG), the electromyogram (EMG), the electroneurogram (ENG), the electrogastrogram (EGG), the action potential (AP), the electroretinogram (ERG), and the electro-oculogram (EOG). These electrical voltages can be measured from electrodes
placed on the skin or within the body. The chapter also covers pulse oximeters and important therapeutic medical devices: artificial cardiac pacemaker, defibrillator, cochlear implant, hemodialysis, lithotripsy, ventilator, anesthesia machine, heart-lung machine, infant incubator, drug delivery and infusion pumps, electrosurgery, and tissue ablation. The chapter also touches on electrical safety, and concludes by highlighting the professional societies and organizations related to this field.

Chapter 9, by Grimnes and Høgetveit, begins with a comprehensive definition of biomedical sensors, their classification, and their characteristics. It focuses on the most common biomedical sensors that are used in close contact with humans, and their applications. Several different sensor technologies are discussed, including: strain gage pressure and forces, piezoelectric sensors, thermistors and thermocouples, pyroelectric sensors, photodiodes, flowmeters, chemical sensors, and biopotential and bioimpedance sensors. In addition, important sensor-related safety topics, like electrical hazards and sensor sterilization, are discussed. Signal processing circuitry and amplifiers, typically used in combination with biomedical sensors, are especially emphasized, together with a brief introduction to common sources of errors. The chapter also includes an overview of the historical background, and a forecast on the future potentials of Biomedical Sensors.

Chapter 10, by Reisner, Brauer, Zheng, Vulpe, Bawa, Alvelo, and Gericke, presents a comprehensive review that would form the basis of a monograph on Bionanotechnology. A judicious choice has been made in this chapter by its authors to identify areas of Bionanotechnology that span a wide range of technological tools and form a basis for the evolving art. Following the historical background, the focus is on bionanotechnology sensors, nano-enabled drug delivery, nanomedicine regulation, biotechnology templates for electronic device architecture, and biosynthesis of nanoparticles. The chapter concludes with a forecast of the future of Bionanotechnology, and sheds light on some professional societies and organizations related to this field.

Chapter 11, by Menciassi and Laschi, defines the science and engineering of Biorobotics, including bio-inspiration and bio-application, which comprises of robot developments aimed at verifying scientific hypotheses and then generating new knowledge, as well as robot developments aimed at precise applications in the medical field. Specifically, the applications of robotics are analyzed in therapy and surgery and in rehabilitation and assistance. In addition to the historical background and state-of-the-art review, the chapter methodically delineates the areas composing biorobotics, the common methodology used for designing and developing biorobots, and the latest achievements in this field. Finally, the chapter provides pointers to professional and scientific societies and organizations within this field.

Chapter 12, by Dyro, presents the origins, development, present status, and future of Clinical Engineering as an applied branch of Biomedical Engineering. The chapter begins with a definition of clinical engineering followed by a historical background and literature overview. Subsequently, a presentation is given on clinical engineering practice as related to: roles and responsibilities of clinical engineers, models of service to hospitals, Information Technology, and medical device connectivity and interoperability. It also includes within the scope of clinical engineering practice the clinical application of technology, health technology and clinical facilities management, standards and regulations, research and development, patient safety, failure analysis, human factors, education and training, and professionalism and ethics. Furthermore, the chapter presents a forecast of future directions and concludes with a description of professional societies and organizations pertaining to the field.

Chapter 13, by Facelli, Hurdle, and Mitchell, provides a broad survey of the complex discipline of Biomedical Informatics – Medical Informatics and Bioinformatics- whereby, medical informatics is used to describe the study and use of computer applications in healthcare, while bioinformatics is used
to describe computer applications focused on biological systems in general. An overview of the field is given with a special focus and added depth in areas that are interesting and illustrative. The chapter places a special emphasis on the key emerging subdisciplines of this broad field such as translational informatics, clinical research informatics, public health informatics, consumer health informatics, and the informatics of the “omics” sciences, systems biology, and nanotechnology. The chapter concludes with a speculation about the future of this field and a listing of some of its key challenges, to end with an identification of some related professional societies and organizations in the field.

Chapter 14, by Bruce, begins by referring to Medical and Biological Analysis as the application of engineering methods of signal processing to measurements from human subjects for defining the differences between normal and pathological signals in order to detect the presence of a disease process, or detect changes in the status of a patient associated with treatment. Within this context, the chapter identifies the sources of biomedical signals and their classification, to be followed with a historical background focusing on clinical applications and early quantitative and engineering approaches. The chapter then presents classical engineering methods addressing signals in one dimension; it emphasizes traditional signal processing methods, such as autocorrelation and cross-correlation functions, and methods based on Fourier analysis because of their long history of successful application for medical and biological analysis. Subsequently, the chapter delineates some contemporary engineering approaches to medical and biological analysis, and concludes by addressing filters and noise removal and signal compensation, due to the fact that filters are frequently encountered in the processing of biomedical signals, and are often embedded in biomedical instrumentation.

Chapter 15, by Wang, Cong, Gao, Zhang, Weir, Xu, and Bennett, presents both fundamental and advanced aspects of the major medical imaging modalities: Computed Tomography (CT), Magnetic Resonance Imaging (MRI), Positron Emission Tomography (PET), Single Photon Emission Computed Tomography (SPECT), Ultrasound (US), and optical imaging. For each of these imaging modalities, the chapter describes methods, representative system architectures, illustrative clinical applications, as well as major research directions. The chapter concludes with a non-exclusive list of representative specialty journals, scientific conferences, and professional societies and organizations within the field of Medical Imaging.

Chapter 16, by Robinson, provides a definition for Neural Engineering and briefly describes its history. An introduction to neuroscientific principles is presented to provide a base for understanding neurally engineered developments. Specific advances in neuroprosthetics are described, including visual prosthetics, cochlear implants, myoelectric artificial limbs, brain computer interfaces, and functional neuromuscular stimulation applications. Other neural engineering applications and the future potential of the field are also considered along with related professional societies and organizations.

Chapter 17, by Nikita and Michmizos, provides an introduction to and an overview of the interdisciplinary field of Modeling, Simulation, and Control of Physiological Systems, whereby research and applications extend from cells to organs and systems, and include linear and nonlinear approaches having time-varying or time-constant variables. Hence, the chapter discusses the major fields of activity in which models of biological systems are engaged. It provides an introduction to important concepts and then illustrates these ideas with examples acquired from physiological systems. The chapter focuses on techniques in modeling that motivate the inclusion of control mechanisms into physiological systems and models. In parallel, it provides methodological approaches and discusses their advantages and limitations in order to motivate the reader to have a hands-on experience on the main modeling aspects covered. The chapter concludes with a forecast of the future of this field.
Chapter 18, by Frigo and Pavan, begins by differentiating Prosthetics and Orthotics as two different disciplines that have as a common objective the recovery of human function through the use of special devices called Prostheses and Orthoses, respectively. As such, the chapter reviews the basic knowledge about prosthetic and orthotic devices with reference to one of the main application areas, namely motor rehabilitation. It provides information about characteristics and main components of prosthetics and orthotics, specifically the biomechanical principles related to designing and fitting these devices to patients. It also addresses the new advances being derived from the advent of new materials and technologies. The state-of-the-art presented in this chapter includes basic concepts and applications that have evolved in the last sixty years, starting from the boost of investment and research that has emerged after the Second World War. In addition to highlighting the recent improvements that are the result of an increased awareness of the problems of disability and handicap and which are continually improving quality of life and autonomy in persons with special needs. The chapter concludes with a forecast of the needs, challenges, and advancements of prosthetic and orthotic devices, and a non-exclusive list of related professional societies and organizations.

As Editor, I hope that the Handbook of Research on Biomedical Engineering Education & Advanced Bioengineering Learning: Interdisciplinary Concepts becomes an icon in the field of Bioengineering/Biomedical Engineering and contributes to the advancement of knowledge of this humanitarian field.

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