

# Preface

The objective of the book is to put forward emerging ideas from biology and mathematics into biomedical engineering applications in general with special attention to the analysis of the human respiratory system. The field of fractional calculus is mature in mathematics and chemistry, but still in infancy in engineering applications. However, the last two decades have been very fruitful in producing new ideas and concepts with applications in biomedical engineering. The reader should find the book a revelation of the latest trends in modeling and identification of the human respiratory parameters for the purpose of diagnostic and monitoring. Of special interest here is the notion of fractal structure, which tells us something about the biological efficiency of the human respiratory system. Related to this notion is the fractal dimension, relating the adaptation of the fractal structure to environmental changes (i.e. disease). Finally, we have the dynamical pattern of breathing, which is then the result of both the structure and the adaptability of the respiratory system.

The distinctive feature of the book is that it offers a bottom-up approach, starting from the basic anatomical structure of the respiratory system and continuing with the dynamic pattern of the breathing. The relations between structure (or the specific changes within it) and fundamental working of the system as a whole are pinned such that the reader can understand their interplay. Moreover, this interplay becomes crucial when alterations at the structural level in the airway caused by disease may require adaptation of the body to the functional requirements of breathing (i.e. to ensure the necessary amount of oxygen to the organs). Adaptation of the human body, and specially of the respiratory system, to various conditions can be thus explained and justified in terms of breathing efficiency.

The motivation for putting together this book is to give by means of the example chosen (i.e. the respiratory system) an impulse to the engineering and medical community in embracing these new ideas and becoming aware of the interaction between these disciplines. The net benefit of reading this book is the advantage of any researcher who wants to stay up to date with the new emerging research trends in biomedical applications. The book offers the reader an opportunity to become aware of a novel, unexplored, and yet challenging research direction.

My intention was to build a bridge between the medical and engineering worlds, to facilitate cross-fertilization. In order to achieve this, I tried to organize the book in the traditional structure of a textbook.

A brief introduction will present the concept of fractional signals and systems to the reader, including a short history of the fractional calculus and its applications in biology and medicine. In this introductory chapter, the notions of fractal structure and fractal dimension will be defined as well.

The second chapter describes the anatomy of the respiratory system with morphological and structural details, as well as lung function tests for evaluating the respiratory parameters with the aim of diagnosis and monitoring. The third chapter will present the notion of respiratory impedance, how it is measured, why it is useful and how we are going to use it in the remainder of the book.

A mathematical basis for modeling air-pressure and air-flow oscillations in the airways is given in the fourth chapter. This model will then be used as a basis for further developments of ladder network models in Chap. 5, thus preserving anatomy and structure of the respiratory system. Simulations of the effects of fractal symmetry and asymmetry on the respiratory properties and the evaluation of respiratory impedance in the frequency domain are also shown.

Chapter 6 will introduce the equivalent mechanical model of the respiratory tree and its implications for evaluating viscoelasticity. Of special importance is the fact that changes in the viscoelastic effects are clearly seen in patients with respiratory insufficiency, hence markers are developed to evaluate these effects and provide insight into the monitoring of the disease evolution. Measurements on real data sets are presented and discussed.

Chapter 7 discusses models which can be used to model the respiratory impedance over a broad range of frequencies, namely ladder network model and a model existing in the literature, for comparison purposes. The upper airway shunt (not part of the actual respiratory system with airways and parenchyma) and its bias effect in the estimated values for the respiratory impedance is presented, along with a characterization on healthy persons and prediction values. Measurements on real data sets are presented and discussed.

Chapter 8 presents the analysis of the breathing pattern and relation to the fractal dimension. Additionally, a link between the fractal structure and the convergence to fractional order models is shown, allowing also a link between the value of the fractional order model and the values of the fractal dimension. In this way, the interplay between structure and breathing patterns is shown. A discussion of this interplay points to the fact that with disease, changes in structure occur, these structural changes implying changes in the work necessary to breath at functional levels. Measurements on real data sets are again presented and discussed.

Chapter 9 introduces methods and protocols to investigate whether moving from the theory of linear system to nonlinear contributions can bring useful insight as regards diagnosis. In this context, measuring frequencies close to the breathing of the patient is more useful than measuring frequencies outside the range of tidal breathing. This also implies that viscoelasticity will be measured in terms of nonlinear effects. The nonlinear artifacts measured in the respiratory impedance, are then

linked to the viscous and elastic properties in the lung parenchyma. Measurements on real data sets are presented and discussed. Chapter 10 summarizes the contributions of the book and point to future perspectives in terms of research and diagnosis methods. In the Appendix, some useful information is given to further support the reader in his/her quest for knowledge.

Finally, I would like to end this preface section with some words of acknowledgment.

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