Preface

This book discusses recent advances in biomedical sensing as well as image analysis and processing techniques so as to develop a unified framework for computer-aided disease diagnosis. One of the aims is to discuss different approaches that will enable us to efficiently and reliably identify different features that are present in biomedical images. Another aim is to provide a generic framework for image classification.

The following four biomedical imaging modalities are considered: terahertz (THz) imaging, dynamic contrast-enhanced MRIs (DCE-MRIs) including functional MRI (fMRI), retinal fundus imaging and optical coherence tomography (OCT). THz imaging is chosen as it is a very promising emergent diagnostic modality that complements MRI. Under certain circumstances, it can also be independently used to identify and assess disease proliferation. OCT is a non-invasive imaging technique relying on low-coherence interferometry to generate in vivo, cross-sectional imagery of ocular tissue, and it complements fundus photography. Furthermore, OCT data sets have a structure similar to that found in THz imaging and MRI. Commonalities in these data structures can be explored by developing a unified multichannel signal processing framework for biomedical image analysis. Integration of complementary data sets provides additional features which can assist in inferring disease proliferation.

This book also provides an account of recent advances in artificial intelligence (AI) algorithms that may be applied to the multichannel framework discussed. Feature extraction and classification methods taking into consideration recent advances in support vector machine (SVM) and extreme learning machine (ELM) classifiers are also explained, and these formulations are extended to higher dimensional spaces for multiclass signal classification. The discussion also provides some future directions for machine learning approaches using Clifford algebra classifiers and deep learning architectures with geometric neurons. These recent advances can potentially lead to particularly powerful artificial intelligence AI algorithms that may one day automate several diagnostic processes.

Because of the multidisciplinary exposure of the subject, this book should be useful to final-year undergraduate or graduate students and research practitioners in

Biomedical Engineering, Applied Physics and Computer Science departments, who have already some familiarity with the topics discussed and are interested in learning about the latest advances on the subject. The different topics covered should also provide new ideas for discipline hopping, improving employability and career progression.

In addition, Chaps. 3–6 this book provides a generic framework for biomedical signal processing and classification which should be useful to computer science practitioners and AI software developers entering the biomedical field. The proposed multichannel framework points towards the direction of developing an open software architecture for signal denoising and feature extraction upon which specialized routines – tailored to different biomedical applications – can be developed. This is also beneficial from a software standardization perspective.

One of the issues commonly encountered in biomedical image analysis is that scientists from different disciplines focus on the different aspects associated with an image. A molecular spectroscopist will be focusing on locations in an image where efficient energy exchange between the excitatory signal and the tissue under study has taken place. This process would include the identification of specific ro-vibrational lines (for gases) or bands (for liquids and solids) as biomarkers under different physiological conditions. In contrast, an engineer would be focusing on signal processing, whereas a computer scientist on identifying the boundaries between different types of tissues or identifying and suppressing artefacts arising from different illumination conditions. In contrast, clinicians would be mostly concerned with the identification of different types and the pathological state of tissue as well as the visualization of small regions in the body and the mapping of opaque objects using a particular imaging technique. All these scientists tend to operate at different levels of complexity across a range of hierarchy levels from molecules all the way to the cellular, tissue, organ or organism level. The diversity of processing algorithms and the fact that modelling at one level of hierarchy does not scale well to higher levels of complexity due to the multiparametric emergent properties of biological media, are major contributing factors that have impeded progress towards automating the diagnostic process. An effort has been made to account for these different perspectives.

This book is, therefore, structured as follows:

Chapter 1 provides a general introduction to THz spectroscopy and then focuses on THz-transient spectrometry. The different system configurations and types of signals recorded are explained. The MRI imaging modality is also introduced. The tensorial nature of the MRI signal is also explained. THz and MRI time series analysis are placed in a common signal processing framework on the basis of the data structures associated with single pixels or voxels. An introduction to retinal fundus imaging as well as optical coherence tomography is also provided. Similarities and differences between these four different measurement modalities are highlighted.

Chapter 2 provides an overview of clinical applications using the four imaging modalities discussed in Chap. 1. This includes biomedical applications of THz spectroscopy and MRI, contrast imaging on the basis of tissue water content, identification of biomarkers and the visualization of tissue oxygenation levels on the basis of the BOLD signal observed through fMRI. In addition, possibilities for combining THz spectroscopy and MRI with other sensing techniques using a multichannel framework are highlighted. Finally, recent advances in the application of fundus imaging to disease diagnosis and the application of OCT imaging for the visualization of increased vascularization in mammograms as well as the detection of abnormalities in infant brains are reported.

The following chapters take the view that the problem of developing automated classifier solutions for assessing disease progression should be seen as the tuning of three different modules that may be individually optimized for particular samples and data sets: the data acquisition imaging module, the data denoising pre-processing and feature extraction module and finally the classifier module. Tuning may be tailored separately for each module according to the features resolved by each measurement modality so as to optimize the classifier learning process.

Chapter 3 discusses different signal denoising methodologies applicable to both THz and MRI systems as well as fundus photography and OCT. Data windowing, apodization, parametric model fitting and multiresolution feature extraction methodologies with wavelets as well as adaptive wavelets for both THz and MRI data sets are also reviewed. The above discussions are effectively focusing on robust feature extraction and selection strategies, firstly from a single pixel perspective and then from an imaging perspective. Benefits from adopting a fractional order calculus approach to detect features in an image are explained. Recent advances in fundus image denoising are also highlighted. A multiresolution image fusion scheme that could be used to combine MRI with THz data sets is proposed. This chapter then discusses several feature selection strategies for both THz and MRI data sets. In the case of THz data sets features in time, frequency or wavelet domains associated with single pixels are considered. In the case of MRI data sets, the discussion focuses on features observed across entire images, taking into consideration textural information. Spatiotemporal correlations across different areas in an image, as identified through fMRI, are discussed. Advances in a graph-theoretical framework that can potentially elucidate such correlations are also mentioned. In addition, feature extraction and selection in retinal fundus imaging and OCT are reviewed.

Chapter 4 discusses recent advances in different classifier methodologies, with an emphasis on complex support vector machine and extreme learning machine approaches. An extension to multidimensional extreme learning machine classifiers is provided. Examples of binary as well as multiclass classification tasks using THz data sets are presented. The performance of other classifiers such as multimodal logistic regression, and naïve Bayesian, in performing classification of THz data sets is compared. In addition, some recent advances in clustering and segmentation techniques for THz data sets as well as for fundus images are discussed. Current methods for automatic retinal vessel classification are highlighted, as it is envisaged that the improved edge detection algorithms discussed in the previous chapters in conjunction with the proposed classification methodologies, can lead to better discrimination between arteries and veins. Finally, this chapter discusses some recent advances in automated image classification using performance criteria directly developed by clinicians.

Chapter 5 provides a more in-depth analysis of MRI data sets. A recently developed spatiotemporal enhancement methodology for DCE-MRIs that makes use of a tensorial multichannel framework is explained. Examples from breast tumour reconstruction are provided to showcase the proposed methodology. It is shown that tumour voxels registered in three-dimensional space can be reconstructed better after increasing contrast from background images using the proposed methodology. The algorithm can be used to perform both feature extraction and image registration. This chapter also discusses the general structure of supervised learning algorithms for functional MRI data sets. Advances in supervised multivariate learning from fMRI data sets that promise to further elucidate brain disorders are discussed. Finally, the general structure of topological graph kernels in functional connectivity networks is explained. The prospects for developing machine learning algorithms that would automatically provide spatiotemporal associations of brain activity across different regions using graph theory methodologies are discussed. A more critical view of what may be achieved taking into consideration limitations in the fMRI measurement modality is provided. Finally, some recent advances from the computer vision community of relevance are highlighted as possible future research directions.

Chapter 6 provides an outlook to future multichannel classifiers, incorporating multiple features in their input space. Such approaches are also suitable for classifying multidimensional tensorial data sets. The discussion focuses on Clifford algebra-based feature classification. A multichannel approach enables the fusion of information acquired from multiple images at different time stamps, so it can potentially elucidate disease progression. In addition, this chapter discusses recent advances in deep learning as related to MRI as well as THz imaging data sets. The use of geometric neurons which can combine information from complementary sensing modalities is highlighted as an important future research direction for feature extraction and classification in MRI. In addition, the proposed Clifford framework could also benefit the THz imaging community, providing improved classification results when these systems undergo clinical trials.

Chapter 7 provides some concluding remarks related to the recent advances in signal processing and classification across the four imaging modalities discussed throughout this book. It aims to highlight how progress in each of the above research areas can be shared to accelerate progress across different biomedical imaging modalities. Furthermore, this chapter summarizes some of the main aspects of the unified multichannel framework that was developed throughout this book. Finally, this chapter concludes by providing some future directions towards a generic framework for the automated quantitative assessment of disease proliferation. It is envisioned that in the near future, a combination of several biomedical sensing modalities will be integrated through sensor fusion and that artificial intelligence techniques will efficiently use the complementary information, to improve disease diagnosis.

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