MEDICAL IMAGE ANALYSIS

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SECOND EDITION

MEDICAL IMAGE ANALYSIS

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To my father
Chandar Bhan Dhawan

It is a *devotion!*

CONTENTS

PREFACE TO THE SECOND EDITION

Radiological sciences in the last two decades have witnessed a revolutionary progress in medical imaging and computerized medical image processing. The development and advances in multidimensional medical imaging modalities such as X-ray mammography, X-ray computed tomography (X-ray CT), single photon computed tomography (SPECT), positron emission tomography (PET), ultrasound, magnetic resonance imaging (MRI), and functional magnetic resonance imaging (fMRI) have provided important radiological tools in disease diagnosis, treatment evaluation, and intervention for significant improvement in health care. The development of imaging instrumentation has inspired the evolution of new computerized methods of image reconstruction, processing, and analysis for better understanding and interpretation of medical images. Image processing and analysis methods have been used to help physicians to make important medical decisions through physician–computer interaction. Recently, intelligent or model-based quantitative image analysis approaches have been explored for computer-aided diagnosis to improve the sensitivity and specificity of radiological tests involving medical images.

Medical imaging in diagnostic radiology has evolved as a result of the significant contributions of a number of disciplines from basic sciences, engineering, and medicine. Computerized image reconstruction, processing, and analysis methods have been developed for medical imaging applications. The application-domain knowledge has been used in developing models for accurate analysis and interpretation.

In this book, I have made an effort to cover the fundamentals of medical imaging and image reconstruction, processing, and analysis along with brief descriptions of recent developments. Although the field of medical imaging and image analysis has a wide range of applications supported by a large number of advanced methods, I have tried to include the important developments with examples and recent references. The contents of the book should enable a reader to establish basic as well as advanced understanding of major approaches. The book can be used for a senior undergraduate or graduate-level course in medical image analysis and should be helpful in preparing the reader to understand the research issues at the cutting edge. Students should have some knowledge of probability, linear systems, and digital signal processing to take full advantage of the book. References are provided at the end of each chapter. Laboratory exercises for implementation in the MATLAB environment are included. A library of selected radiological images and MATLAB programs demonstrating medical image processing and analysis tasks can be obtained from the following ftp site:

ftp://ftp.wiley.com/public/sci_tech_med/medical_image/

Readers can download Imagepro MATLAB interface files to be installed with MATLAB software to provide a Graphical User Interface (GUI) to perform several image processing functions and exercises described in this book. This ftp site also contains several medical image databases with X-ray mammography, X-ray CT, MRI, and PET images of the brain or full body scans of human patients. Figures included in this book with color or black-and-white illustrations are provided in a separate folder. Additional supporting material includes Microsoft Power-Point slides for sample lectures. Thanks to Wiley-IEEE Press for providing and maintaining the ftp site for this book.

I am pleased that the first edition of this book, published in 2003, was very well received and used as a textbook in many universities worldwide. I have carefully revised and expanded the second edition with several new sections and additional material to provide a stronger and broader foundation to readers and students. Chapter 4 of the first edition, which included all four major medical imaging modalities (X-ray, MRI, nuclear medicine, and ultrasound), is now expanded into four individual chapters focused on each modality in greater detail. Several new sections with more details on principles of feature selection and classification have been added in chapters covering the image processing and analysis part of the book.

Chapter 1 presents an overview of medical imaging modalities and their role in radiology and medicine. It introduces the concept of a multidisciplinary paradigm in intelligent medical image analysis. Medical imaging modalities are presented according to the type of signal used in image formation.

Chapter 2 describes the basic principles of image formation and reviews the essential mathematical foundation and transforms. Additional methods such as wavelet transforms and neural networks are not described in this chapter but are explained in later chapters with applications to medical image enhancement, segmentation, and analysis.

Chapter 3 provides an overview of electromagnetic (EM) interaction of energy particles with matter and presents basic principles of detection and measurements in medical imaging.

Chapter 4 describes the principles, instrumentation, and data acquisition methods of X-ray imaging modalities including X-ray radiograph imaging, X-ray mammography, and X-ray CT.

Chapter 5 provides a complete spectrum of MRI modalities including fMRI and diffusion tensor imaging (DTI). Instrumentation and imaging pulse sequences are discussed.

Chapter 6 discusses nuclear medicine imaging modalities including SPECT and PET with more details on detectors and data acquisition systems.

Chapter 7 provides ultrasound imaging principles and methods for real-time imaging. Data acquisition and instrumentation control systems for ultrasound imaging are discussed with dynamic medical imaging applications.

Chapter 8 presents various image reconstruction algorithms used and investigated in different imaging modalities. It starts with the introduction of two-dimensional and three-dimensional image reconstruction methods using the Radon transform. The chapter then continues with the iterative and model-based reconstruction methods.

Chapter 9 starts with the preliminaries in image processing and enhancements. Various methods for image smoothing and enhancement, to improve image quality for visual examination as well as computerized analysis, are described.

Chapter 10 presents the image segmentation methods for edge and region feature extraction and representation. Advanced and model-based methods for image segmentation using wavelet transform and neural networks are described.

Chapter 11 presents feature extraction and analysis methods for qualitative and quantitative analysis and understanding. The role of using a priori knowledge in adaptive, model-based, and interactive medical image processing methods is emphasized. These methods are discussed for classification, quantitative analysis, and interpretation of radiological images. Recent approaches with neural network-based image analysis and classification are also presented.

Chapter 12 describes recent advances in multimodality medical image registration and analysis. Emphasis is given on model-based and interactive approaches for better performance in registering multidimensional multimodality brain images. Registration of brain images is discussed in detail as an example of image registration methods.

Chapter 13 describes multidimensional methods for image visualization. Feature-based surface and volume rendering methods as well as intelligent adaptive methods for dynamic visualization are presented. Recent advances in multiparameter visualization with virtual reality-based navigation are also presented.

Chapter 14 presents some remarks on current and future trends in medical imaging, processing, analysis, and interpretation and their role in computer-aided-diagnosis, image-guided surgery, and other radiological applications. Recent advances in multispectral optical imaging are also introduced.

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