Preface

The field of medical imaging advances so rapidly that all of those working in it, scientists, engineers, physicians, educators, and others, need to frequently update their knowledge to stay abreast of developments. While journals and periodicals play a crucial role in this, more extensive, integrative publications that connect fundamental principles and new advances in algorithms and techniques to practical applications are essential. Such publications have an extended life and form durable links in connecting past procedures to the present, and present procedures to the future. This book aims to meet this challenge and provide an enduring bridge in the ever expanding field of medical imaging.

This book is designed for end users in the field of medical imaging, who wish to update their skills and understanding with the latest techniques in image analysis. The book emphasizes the conceptual framework of image analysis and the effective use of image processing tools. It is designed to assist cross-disciplinary dialog both at graduate and at specialist levels, between all those involved in the multidisciplinary area of digital image processing, with a bias toward medical applications. Its aim is to enable new end users to draw on the expertise of experts across the specialization gap.

To accomplish this, the book uses applications in a variety of fields to demonstrate and consolidate both specific and general concepts, and to build intuition, insight, and understanding. It presents a detailed approach to each application while emphasizing the applicability of techniques to other research areas. Although the chapters are essentially self-contained, they reference other chapters to form an integrated whole. Each chapter uses a pedagogical approach to ensure conceptual learning before introducing specific techniques and "tricks of the trade".

The book is unified by the theme foreshadowed in the title "Medical Image Processing: Techniques and Applications." It consists of a collection of specialized topics, each presented by a specialist in the field. Each chapter is split into sections and subsections, and begins with an introduction to the topic, method, or technology. Emphasis is placed not only on the background theory but also on the practical aspects of the method, the details necessary to implement the technique, and limits of applicability. The chapter then introduces selected more advanced applications of the topic, method, or technology, leading toward recent achievements and unresolved questions in a manner that can be understood by a reader with no specialist knowledge in that area.

Chapter 1, by Dougherty, presents a brief overview of medical image processing. He outlines a number of challenges and highlights opportunities for further development.

A number of image analysis packages exist, both commercial and free, which make use of libraries of routines that can be assembled/mobilized/concatenated to automate an image analysis task. Chapter 2, by Luengo, Malm, and Bengtsson, introduces one such package, DIPimage, which is a toolbox for MatLab that incorporates a GUI for automatic image display and a convenient drop-down menu of common image analysis functions. The chapter demonstrates how one can quickly develop a solution to automate a common assessment task such as counting cancerous cells in a Pap smear.

Segmentation is one of the key tools in medical image analysis. The main application of segmentation is in delineating an organ reliably, quickly, and effectively. Chapter 3, by Couprie, Najman and Talbot, presents very recent approaches that unify popular discrete segmentation methods.

Deformable models are a promising method to handle the difficulties in segmenting images that are contaminated by noise and sampling artifact. The model is represented by an initial curve (or surface in three dimensions (3D)) in the image which evolves under the influence of internal energy, derived from the model geometry, and an external force, defined from the image data. Segmentation is then achieved by minimizing the sum of these energies, which usually results in a smooth contour. In Chapter 4, Alfiansyah presents a review of different deformable models and issues related to their implementations. He presents some examples of the different models used with noisy medical images.

Over the past two decades, many authors have investigated the use of MRI for the analysis of body fat and its distribution. However, when performed manually, accurate isolation of fat in MR images can be an arduous task. In order to alleviate this burden, numerous segmentation algorithms have been developed for the quantification of fat in MR images. These include a number of automated and semi-automated segmentation algorithms. In Chapter 5, Costello and Kenny discuss some of the techniques and models used in these algorithms, with a particular emphasis on their application and implementation. The potential impact of artifacts such as intensity inhomogeneities, partial volume effect (PVE), and chemical shift artifacts on image segmentation are also discussed.

An increasing portion of medical imaging problems concern thin objects, and particularly vessel filtering, segmentation, and classification. Example applications include vascular tree analysis in the brain, the heart, or the liver, the detection of aneurysms, stenoses, and arteriovenous malformations in the brain, and coronal tree analysis in relation to the prevention of myocardial infarction. Thin, vessel-like objects are more difficult to process in general than most images features, precisely because they are thin. They are prone to disappear when using many common image analysis operators, particularly in 3D. Chapter 6, by Tankyevych, Talbot, Passat, Musacchio, and Lagneau, introduces the problem of cerebral vessel filtering and detection in 3D and describes the state of the art from filtering to segmentation, using local orientation, enhancement, local topology, and scale selection. They apply both linear and nonlinear operators to atlas creation.

Automated detection of linear structures is a common challenge in many computer vision applications. Where such structures occur in medical images, their measurement and interpretation are important steps in certain clinical decision-making tasks. In Chapter 7, Dabbah, Graham, Malik, and Efron discuss some of the well-known linear structure detection methods used in medical imaging. They describe a quantitative method for evaluating the performance of these algorithms in comparison with their newly developed method for detecting nerve fibers in images obtained using *in vivo* corneal confocal microscopy (CCM).

Advances in linear feature detection have enabled new applications where the reliable tracing of line-like structures is critical. This includes neurite identification in images of brain cells, the characterization of blood vessels, the delineation of cell membranes, and the segmentation of bacteria under high resolution phase contrast microscopy. Linear features represent fundamental image analysis primitives. In Chapter 8, Domanski, Sun, Lagerstrom, Wang, Bischof, Payne, and Vallotton introduce the algorithms for linear feature detection, consider the preprocessing and speed options, and show how such processing can be implemented conveniently using a graphical user interface called HCA-Vision. The chapter demonstrates how third parties can exploit these new capabilities as informed users.

Osteoporosis is a degenerative disease of the bone. The averaging nature of bone mineral density measurement does not take into account the microarchitectural deterioration within the bone. In Chapter 9, Haidekker and Dougherty consider methods that allow the degree of microarchitectural deterioration of trabecular bone to be quantified. These have the potential to predict the load-bearing capability of bone.

In Chapter 10, Adam and Dougherty describe the application of medical image processing to the assessment and treatment of spinal deformity, with a focus on the surgical treatment of idiopathic scoliosis. The natural history of spinal deformity and current approaches to surgical and nonsurgical treatment are briefly described, followed by an overview of current clinically used imaging modalities. The key metrics currently used to assess the severity and progression of spinal deformities from medical images are presented, followed by a discussion of the errors and uncertainties involved in manual measurements. This provides the context for an analysis of automated and semi-automated image processing approaches to measure spinal curve shape and severity in two and three dimensions.

In Chapter 11, Cree and Jelinek outline the methods for acquiring and pre-processing of retinal images. They show how morphological, wavelet, and fractal methods can be used to detect lesions and indicate the future directions of research in this area.

The appearance of the retinal blood vessels is an important diagnostic indicator for much systemic pathology. In Chapter 12, Iorga and Dougherty show that the tortuosity of retinal vessels in patients with diabetic retinopathy correlates with the number of detected microaneurysms and can be used as an alternative indicator of the severity of the disease. The tortuosity of retinal vessels can be readily measured in a semi-automated fashion and avoids the segmentation problems inherent in detecting microaneurysms.

With the increasing availability of highly resolved isotropic 3D medical image datasets, from sources such as MRI, CT, and ultrasound, volumetric image rendering techniques have increased in importance. Unfortunately, volume rendering is computationally demanding, and the ever increasing size of medical image datasets has meant that direct approaches are unsuitable for interactive clinical use. In Chapter 13, Zhang, Peters, and Eagleson describe volumetric visualization pipelines and provide a comprehensive explanation of novel rendering and classification algorithms, anatomical feature and visual enhancement techniques, dynamic multimodality rendering and manipulation. They compare their strategies with those from the published literatures and address the advantages and drawbacks of each in terms of image quality and speed of interaction.

In Chapter 14, Bones and Wu describe the background motivation for adopting sparse sampling in MRI and show evidence of the sparse nature of biological image data sets. They briefly present the theory behind parallel MRI reconstruction, compressive sampling, and the application of various forms of prior knowledge to image reconstruction. They summarize the work of other groups in applying these concepts to MRI and then describe their own contributions. They finish with a brief conjecture on the possibilities for future development in the area.

In Chapter 15, Momot, Pope, and Wellard discuss the fundamentals of diffusion tensor imaging (DTI) in avascular tissues and the key elements of digital processing and visualization of the diffusion data. They present examples of the application of DTI in two types of avascular tissue: articular cartilage and eye lens. Diffusion tensor maps present a convenient way to visualize the ordered microstructure of these tissues. The direction of the principal eigenvector of the diffusion tensor reports on the predominant alignment of collagen fibers in both tissues.

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