Digital Image Processing for Medical Applications

The influence and impact of digital images on modern society is tremendous, and image processing is now a critical component in science and technology. The rapid progress in computerized medical image reconstruction, and the associated developments in analysis methods and computer-aided diagnosis, has propelled medical imaging into one of the most important sub-fields in scientific imaging.

This text is intended for use in a first course in image processing and analysis for final-year undergraduate or first-year graduate students. It takes its motivation from medical applications and uses real medical images and situations to clarify concepts and to build intuition and understanding. Designed for readers who will become end users of digital image processing, the effective use of image processing tools is emphasized. An overview of the fundamentals of the most important clinical imaging modalities in use is included to provide a context, and to illustrate how the images are produced and acquired. Through using this text, students will understand why they are undertaking particular operations, and practical computer-based activities will enable them to see in real time how operations affect real images.

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Preface

The influence and impact of digital images on modern society, science, technology and art are tremendous. Image processing has become such a critical component in contemporary science and technology that many tasks would not be attempted without it. It is a truly interdisciplinary subject that draws from synergistic developments involving many disciplines and is used in medical imaging, microscopy, astronomy, computer vision, geology and many other fields.

The rapid and continuing progress in computerized medical image reconstruction, and the associated developments in analysis methods and computer-aided diagnosis, have propelled medical imaging into one of the most important sub-fields in scientific imaging. This book takes its motivation from medical applications and uses real medical images and situations to clarify and consolidate concepts and to build intuition, insight and understanding. An overview of the fundamentals of the most important clinical imaging modalities in use is included to provide a context, and to illustrate how the images are produced and acquired.

This is a text for use in a first practical course in image processing and analysis, for final-year undergraduate or first-year graduate students with a background in biomedical engineering, computer science, radiologic sciences or physics. Designed for readers who will become "end users" of digital image processing in the biomedical sciences, it emphasizes the conceptual framework and the effective use of image processing tools and uses mathematics as a tool, minimizing the advanced mathematical development of other textbooks.

Discussions of the major medical imaging modalities enable students to understand the diagnostic tasks for which images are needed and the typical distortions and artifacts associated with each modality. This knowledge then motivates the presentation of the techniques needed to reverse distortions, minimize artifacts and enhance important features. Students understand *why* they are undertaking particular operations, and the practical activities enable them to see in real time *how* operations affect real images. Image processing is a hands-on discipline, and the best way to learn is by doing. Theory and practice are linked, each reinforcing the other.

The key distinguishing features of the book are as follows.

- Its pedagogical approach combines intuition with problem-solving, and emphasizes conceptual learning, i.e. understanding the "big picture," rather than getting overwhelmed with the details.
- Overviews summarize the essential purpose of the material covered in each chapter.
- Learning objectives list the specific knowledge and skills to be acquired.

- Practical computer-based activities, referred to in each chapter, build intuition, skills and confidence. They can be used by the instructor for class demonstrations and/or by the students as hands-on activities.
- Accessible end-of-chapter problems reinforce and consolidate understanding.
- Only a modest background in mathematics and science, at the level of College/ University entry, is assumed.

Courses supported and organization of the text

The text is based on courses in image analysis, pattern recognition and medical imaging that I teach at California State University, Channel Islands, and have taught previously at the Health Sciences Center, Kuwait University. The material is more than can comfortably be covered in a single-semester course, and can be fine-tuned to specific courses and audiences. The book can be used to support several different courses, by emphasizing different chapters and skimming or avoiding others altogether. For example, a course for biomedical engineers or radiologic science students would include all the material from Chapters 3 and 4, and might skim through Chapters 10 and 11. It would benefit from an early visit to a local hospital or imaging center to view image acquisition and analysis in a clinical setting. A few invited talks from medical professionals, such as radiologists, pathologists or oncologists, could be included to add to the clinical perspective. A course in image analysis for computer scientists or physicists would probably downplay Chapters 3–4, omit Chapters 13 and 14, skim through Chapter 11, and ensure that all the activities and end-of-chapter problems were attempted. And a course in pattern recognition, or a graduate course, would concentrate on Chapters 9–12 and the material in the appendices.

Each chapter starts with an overview of its contents and a list of its objectives. Concepts, techniques and algorithms are introduced and then applied to typical medical imaging problems. The material is integrated with a number of practical computer-based activities, arranged at the end of each chapter, and supplemented by exercises, mostly numerical, for the reader to verify his/her understanding. Worked examples are included in separate boxed sections.

The book comprises four parts. Part I is an introduction to image processing. It provides an overview of the field and its many applications (Chapter 1), explains how digital images are acquired and discusses their characteristics (Chapter 2). It explains how medical images are produced, using both ionizing (Chapter 3) and non-ionizing radiation (Chapter 4), and discusses the most important clinical imaging modalities.

Part II explains the fundamental concepts of image processing. Gray-level histograms are introduced, and display look-up tables (LUTs) discussed in terms of changing image appearance (Chapter 5). Image enhancement in both the spatial and frequency domains is addressed in Chapters 6 and 7, respectively. Chapter 8 discusses techniques which aim to restore a degraded image to its original condition.

Part III deals with image analysis and visualization. Morphology is introduced as an image analysis tool in Chapter 9, illustrating its applicability to medical imaging problems.

Segmentation techniques are discussed in Chapter 10, which leads into feature extraction and classification in Chapter 11. Chapter 12 discusses how the three-dimensional structure of internal organs can be visualized and displayed convincingly on a two-dimensional computer monitor.

Part IV discusses a number of specific applications in medicine, indicating the image analysis techniques that are being used (Chapter 13), and considers the trends and ongoing developments in medical imaging (Chapter 14).

Three appendices provide further details (on the Fourier transform, set theory and probability, and shape and texture) relevant to the techniques explored.

Computer-based activities

ImageJ is a very popular public domain (http://rsb.info.nih.gov/ij/) Java image processing and analysis program that was developed at the National Institutes of Health. It has a convenient and intuitive graphical user interface (GUI), and has been chosen for its ease of use for the computer-based imaging activities which are integrated within the book. Its source code is freely available, so that users have complete freedom to run, copy, distribute, study, change and improve the software (see www.gnu.org/philosophy/free-sw.html). At a more basic level it allows users to collect imaging operations together in macros, which are stored as text files and are easy to write, edit and debug.

However, most of the exercises can be easily duplicated to run in an alternative environment, such as Matlab if the Matlab Toolbox/GUI, DipImage (available as a free download to non-commercial use at www.diplib.org/home2224) is used; without DipImage, the necessary programming in MatLab can be tedious and distract from learning the imaging fundamentals.

The ImageJ homepage contains links to documentation and downloads. ImageJ runs on any computer with a Java 1.1 or later virtual machine, but in order to be able to compile additional "plugins" (optional extras) and manage memory more efficiently, it is recommended that it be downloaded together with the full Java runtime environment. The examples in this book use an expansion of ImageJ version 1.37v with Java 1.5.0 (a total download of about 20 MB). Additional plugins can be downloaded from the ImageJ site or others, and comprise compiled java files (named *.class) which need to be placed in the "Plugins" sub-folder of the ImageJ folder.

It is recommended that you download the latest version of ImageJ bundled with Java 1.5.0 from http://rsb.info.nih.gov/ij/download.html. Once unzipped and installed in a directory called ImageJ, a shortcut will be installed on your desktop and in your Start/All Programs menu. The ImageJ core program (ij.jar) is frequently upgraded. You should visit the ImageJ website (http://rsb.info.nih.gov/ij/) routinely to check for upgrades, download the upgraded *.zip file and use the extracted ij.jar to replace the current ij.jar file. (You can find your current version by opening ImageJ and going to Help, About ImageJ; close ImageJ before replacing the ij.jar file with an upgrade.)

A collection of plugins has been collated, comprising some freely available from the Plugins download site (http://rsb.info.nih.gov/ij/plugins/index.html) and others written specifically for this text. They are available at the book website in folders with names such as Ch.5 Plugins (to facilitate the computer activities in Chapter 5); copy them into the ImageJ folder called "Plugins" on your computer. These additional plugins become available in the Plugins menu when ImageJ is next run. Most of the computer activities require images for processing; these can be found at the book website in folders with names such as Ch.5 Activities, and should be copied to the ImageJ directory in your computer for easy access. After first opening ImageJ, go to Edit, Options, Memory and change the memory allocated to ImageJ to equal 75% of your computer's RAM, which you can find from My Computer, View System Properties, Hardware.

The computer-based activities are referred to within the text and are collected at the end of each chapter. The required images are referred to in bold Courier New font, e.g. **`lena`**, and the ImageJ menu functions are referred to in bold Arial, e.g. **Image/Process/Threshold …** There are also some computer activities which use other resources, including video files and Excel spreadsheets.

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Frontmatter
More information

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