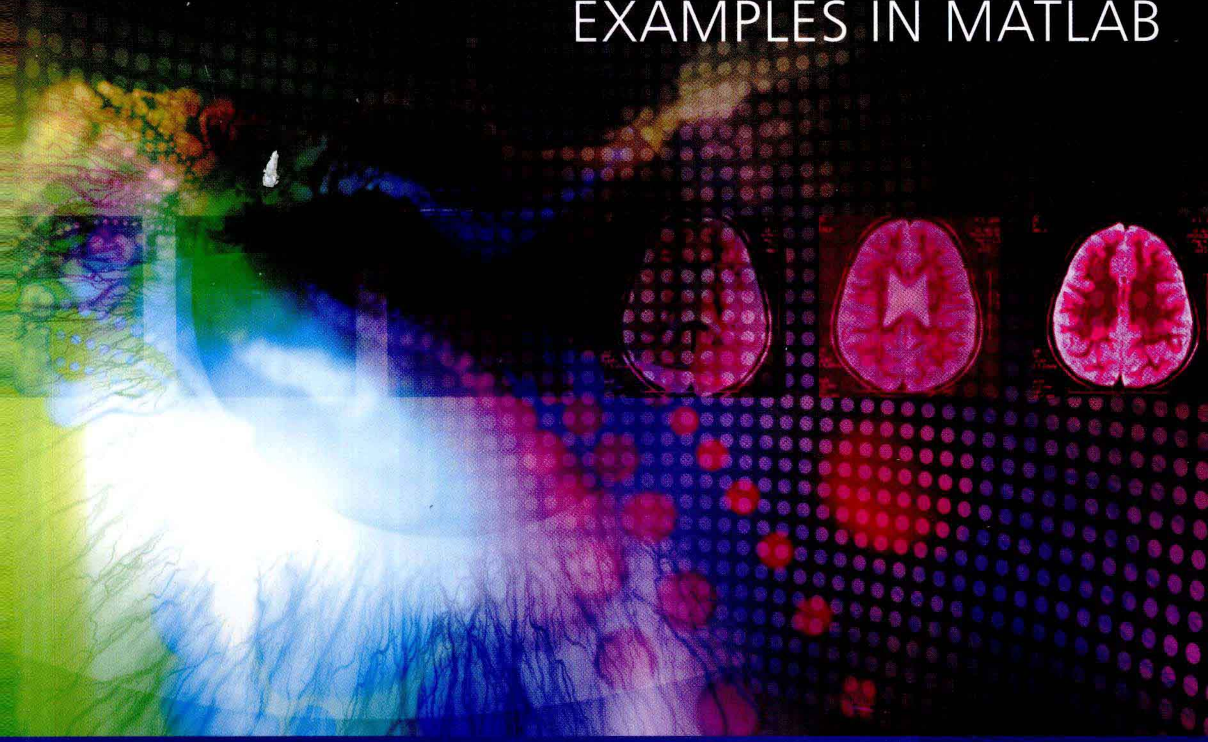
CHRIS SOLOMON | TOBY BRECKON

FUNDAMENTALS OF DIGITAL IMAGE PROCESSING

A PRACTICAL APPROACH WITH EXAMPLES IN MATLAB



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Fundamentals of Digital Image Processing

A Practical Approach with Examples in Matlab

Chris Solomon
School of Physical Sciences, University of Kent, Canterbury, UK
Toby Breckon
School of Engineering, Cranfield University, Bedfordshire, UK

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Fundamentals of Digital Image Processing

Preface

Scope of this book

This is an introductory text on the science *(and art)* of image processing. The book also employs the Matlab programming language and toolboxes to illuminate and consolidate some of the elementary but key concepts in modern image processing and pattern recognition.

The authors are firm believers in the old adage, "***Hear** and forget*. . ., ***See** and remember*. . ., ***Do** and know*". For most of us, it is through good examples and gently guided experimentation that we really learn. Accordingly, the book has a large number of carefully chosen examples, graded exercises and computer experiments designed to help the reader get a real grasp of the material. All the program code (.m files) used in the book, corresponding to the examples and exercises, are made available to the reader/course instructor and may be downloaded from the book's dedicated web site – www.fundipbook.com.

Who is this book for?

For undergraduate and graduate students in the technical disciplines, for technical professionals seeking a direct introduction to the field of image processing and for instructors looking to provide a hands-on, structured course. This book intentionally starts with simple material but we also hope that relative experts will nonetheless find some interesting and useful material in the latter parts.

Aims

What then are the specific aims of this book ? Two of the principal aims are –

- To introduce the reader to some of the key concepts and techniques of modern image processing.

- To provide a framework within which these concepts and techniques can be understood by a series of examples, exercises and computer experiments.

These are, perhaps, aims which one might reasonably expect from *any* book on a technical subject. However, we have one further aim namely to provide the reader with the fastest, most direct route to acquiring a real hands-on understanding of image processing. We hope this book will give you a real fast-start in the field.

Assumptions

We make no assumptions about the reader's mathematical background beyond that expected at the undergraduate level in the technical sciences – ie reasonable competence in calculus, matrix algebra and basic statistics.

Why write this book?

There are already a number of excellent and comprehensive texts on image processing and pattern recognition and we refer the interested reader to a number in the appendices of this book. There are also some exhaustive and well-written books on the Matlab language. What the authors felt was lacking was *an image processing book which combines a simple exposition of principles with a means to quickly test, verify and experiment with them in an instructive and interactive way.*

In our experience, formed over a number of years, Matlab and the associated image processing toolbox are extremely well-suited to help achieve this aim. It is simple but powerful and its key feature in this context is that it enables one to *concentrate on the image processing concepts and techniques* (i.e. the real business at hand) while keeping concerns about programming syntax and data management to a minimum.

What is Matlab?

Matlab is a programming language with an associated set of specialist software toolboxes. It is an industry standard in scientific computing and used worldwide in the scientific, technical, industrial and educational sectors. Matlab is a commercial product and information on licences and their cost can be obtained direct by enquiry at the web-site www.mathworks.com. Many Universities all over the world provide site licenses for their students.

What knowledge of Matlab is required for this book?

Matlab is very much part of this book and we use it extensively to demonstrate how certain processing tasks and approaches can be quickly implemented and tried out in practice. Throughout the book, we offer comments on the Matlab language and the best way to achieve certain image processing tasks in that language. Thus the learning of concepts in image processing and their implementation within Matlab go hand-in-hand in this text.

Is the book any use then if I don't know Matlab?

Yes. This is fundamentally a book about image processing which aims to make the subject accessible and practical. It is not a book about the Matlab programming language. Although some prior knowledge of Matlab is an advantage and will make the practical implementation easier, we have endeavoured to maintain a self-contained discussion of the concepts which will stand up apart from the computer-based material.

If you have not encountered Matlab before and you wish to get the maximum from this book, please refer to the Matlab and Image Processing primer on the book website (http://www.fundipbook.com). This aims to give you the essentials on Matlab with a strong emphasis on the basic properties and manipulation of images.

Thus, you do not have to be knowledgeable in Matlab to profit from this book.

Practical issues

To carry out the vast majority of the examples and exercises in the book, the reader will need access to a current licence for ***Matlab*** and the ***Image Processing Toolbox*** only.

Features of this book and future support

This book is accompanied by a dedicated website (http://www.fundipbook.com). The site is intended to act as a point of contact with the authors, as a repository for the code examples (Matlab .m files) used in the book and to host additional supporting materials for the reader and instructor.

About the authors

Chris Solomon gained a B.Sc in theoretical physics from Durham University and a Ph.D in Medical imaging from the Royal Marsden Hospital, University of London. Since 1994, he has been on the Faculty at the School of Physical Sciences where he is currently a Reader in Forensic Imaging. He has broad research interests focussing on evolutionary and genetic algorithms, image processing and statistical learning methods with a special interest in the human face. Chris is also Technical Director of Visionmetric Ltd, a company he founded in 1999 and which is now the UK's leading provider of facial composite software and training in facial identification to police forces. He has received a number of UK and European awards for technology innovation and commercialisation of academic research.

Toby Breckon holds a Ph.D in Informatics and B.Sc in Artificial Intelligence and Computer Science from the University of Edinburgh. Since 2006 he has been a lecturer in image processing and computer vision in the School of Engineering at Cranfield University. His key research interests in this domain relate to 3D sensing, real-time vision, sensor fusion, visual surveillance and robotic deployment. He is additionally a visiting member of faculty at *Ecole Supérieure des Technologies Industrielles Avancées* (France) and has held visiting faculty positions in China and Japan. In 2008 he led the development of image-based automatic threat detection for the winning Stellar Team system in the UK MoD Grand Challenge. He is a Chartered Engineer (CEng) and an Accredited Imaging Scientist (AIS) as an Associate of the Royal Photographic Society (ARPS).

Thanks

The authors would like to thank the following people and organisations for their various support and assistance in the production of this book: the authors families and friends for their support and (frequent) understanding, Professor Chris Dainty (National University of Ireland), Dr. Stuart Gibson (University of Kent), Dr. Timothy Lukins (University of Edinburgh), The University of Kent, Cranfield University, VisionMetric Ltd and Wiley-Blackwell Publishers.

For further examples and exercises see http://www.fundipbook.com

Using the book website

There is an associated website which forms a vital supplement to this text. It is:

www.fundipbook.com

The material on the site is mostly organised by chapter number and this contains –

EXERCISES: intended to consolidate and highlight concepts discussed in the text. Some of these exercises are numerical/conceptual, others are based on Matlab.

SUPPLEMENTARY MATERIAL: Proofs, derivations and other supplementary material referred to in the text are available from this section and are intended to consolidate, highlight and extend concepts discussed in the text.

Matlab CODE: The Matlab code to all the examples in the book as well as the code used to create many of the figures are available in the Matlab code section.

IMAGE DATABASE: The Matlab software allows direct access and use to a number of images as an integral part of the software. Many of these are used in the examples presented in the text.

We also offer a modest repository of images captured and compiled by the authors which the reader may freely download and work with. Please note that some of the example Matlab code contained on the website and presented in the text makes use of these images. **You will therefore need to download these images to run some of the Matlab code shown.**

We strongly encourage you to make use of the website and the materials on it. It is a vital link to making your exploration of the subject both practical and more in-depth. Used properly, it will help you to get much more from this book.

Contents

1

Representation

In this chapter we discuss the representation of images, covering basic notation and information about images together with a discussion of standard image types and image formats. We end with a practical section, introducing Matlab's facilities for reading, writing, querying, converting and displaying images of different image types and formats.

1.1 What is an image?

A digital image can be considered as a discrete representation of data possessing both spatial (layout) and intensity (colour) information. As we shall see in Chapter 5, we can also consider treating an image as a multidimensional signal.

1.1.1 Image layout

The two-dimensional (2-D) discrete, digital image $I(m,n)$ represents the response of some sensor (or simply a value of some interest) at a series of fixed positions ($m = 1,2,\ldots,M$; $n = 1,2,\ldots,N$) in 2-D Cartesian coordinates and is derived from the 2-D continuous spatial signal $I(x,y)$ through a sampling process frequently referred to as discretization. Discretization occurs naturally with certain types of imaging sensor (such as CCD cameras) and basically effects a local averaging of the continuous signal over some small (typically square) region in the receiving domain.

The indices m and n respectively designate the rows and columns of the image. The individual picture elements or pixels of the image are thus referred to by their 2-D (m,n) index. Following the Matlab® convention, $I(m,n)$ denotes the response of the pixel located at the mth row and nth column starting from a top-left image origin (see Figure 1.1). In other imaging systems, a column–row convention may be used and the image origin in use may also vary.

Although the images we consider in this book will be discrete, it is often theoretically convenient to treat an image as a continuous spatial signal: $I(x,y)$. In particular, this sometimes allows us to make more natural use of the powerful techniques of integral and differential calculus to understand properties of images and to effectively manipulate and

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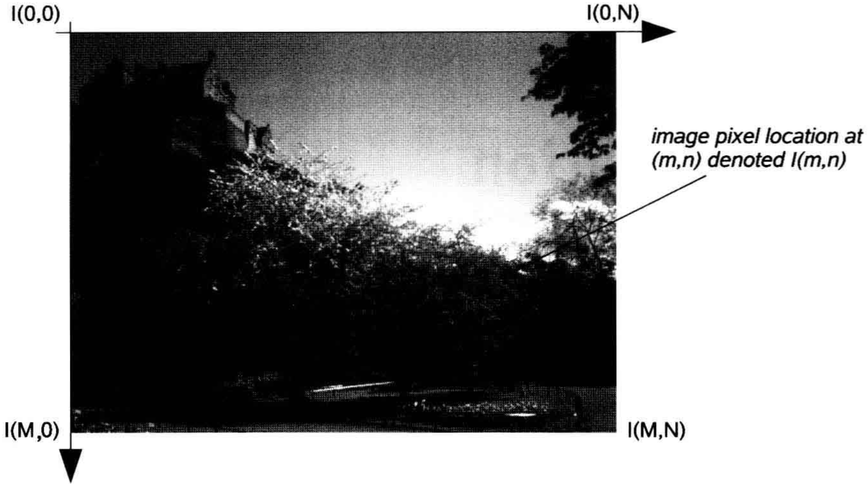

Figure 1.1 The 2-D Cartesian coordinate space of an M x N digital image

process them. Mathematical analysis of discrete images generally leads to a linear algebraic formulation which is better in some instances.

The individual pixel values in most images do actually correspond to some physical response in real 2-D space (e.g. the optical intensity received at the image plane of a camera or the ultrasound intensity at a transceiver). However, we are also free to consider images in abstract spaces where the coordinates correspond to something other than physical space and we may also extend the notion of an image to three or more dimensions. For example, medical imaging applications sometimes consider full three-dimensional (3-D) reconstruction of internal organs and a time sequence of such images (such as a beating heart) can be treated (if we wish) as a single four-dimensional (4-D) image in which three coordinates are spatial and the other corresponds to time. When we consider 3-D imaging we are often discussing spatial volumes represented by the image. In this instance, such 3-D pixels are denoted as voxels (volumetric pixels) representing the smallest spatial location in the 3-D volume as opposed to the conventional 2-D image.

Throughout this book we will usually consider 2-D digital images, but much of our discussion will be relevant to images in higher dimensions.

1.1.2 Image colour

An image contains one or more colour channels that define the intensity or colour at a particular pixel location $I(m, n)$.

In the simplest case, each pixel location only contains a single numerical value representing the signal level at that point in the image. The conversion from this set of numbers to an actual (displayed) image is achieved through a colour map. A colour map assigns a specific shade of colour to each numerical level in the image to give a visual representation of the data. The most common colour map is the greyscale, which assigns all shades of grey from black (zero) to white (maximum) according to the signal level. The