

# Computer Processing of Remotely-Sensed Images

## *An Introduction*

Fourth Edition

**Paul M. Mather**

*University of Nottingham*

and

**Magaly Koch**

*Center for Remote Sensing  
Boston University*

 **WILEY-BLACKWELL**  
A John Wiley & Sons, Ltd., Publication



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# Contents

<i>Preface to the First Edition</i>	<i>xi</i>
<i>Preface to the Second Edition</i>	<i>xiii</i>
<i>Preface to the Third Edition</i>	<i>xvii</i>
<i>Preface to the Fourth Edition</i>	<i>xix</i>
<i>List of Examples</i>	<i>xxi</i>
<b>1 Remote Sensing: Basic Principles</b>	<b>1</b>
1.1 Introduction	1
1.2 Electromagnetic Radiation and Its Properties	4
1.2.1 Terminology	4
1.2.2 Nature of Electromagnetic Radiation	6
1.2.3 The Electromagnetic Spectrum	6
1.2.4 Sources of Electromagnetic Radiation	13
1.2.5 Interactions with the Earth's Atmosphere	15
1.3 Interaction with Earth-Surface Materials	17
1.3.1 Introduction	17
1.3.2 Spectral Reflectance of Earth Surface Materials	19
1.4 Summary	26
<b>2 Remote Sensing Platforms and Sensors</b>	<b>29</b>
2.1 Introduction	29
2.2 Characteristics of Imaging Remote Sensing Instruments	31
2.2.1 Spatial Resolution	32
2.2.2 Spectral Resolution	35
2.2.3 Radiometric Resolution	37
2.3 Optical, Near-infrared and Thermal Imaging Sensors	39
2.3.1 Along-Track Scanning Radiometer (ATSR)	40
2.3.2 Advanced Very High Resolution Radiometer (AVHRR) and NPOESS VIIRS	41
2.3.3 MODIS	42
2.3.4 Ocean Observing Instruments	42
2.3.5 IRS LISS	45
2.3.6 Landsat Instruments	46
2.3.7 SPOT Sensors	48
2.3.8 Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER)	53
2.3.9 High-Resolution Commercial and Small Satellite Systems	53
2.4 Microwave Imaging Sensors	58
2.4.1 European Space Agency Synthetic Aperture Spaceborne Radars	62
2.4.2 Radarsat	63
2.4.3 TerraSAR-X and COSMO/SkyMed	64
2.4.4 ALOS PALSAR	65
2.5 Summary	66

<b>3</b>	<b>Hardware and Software Aspects of Digital Image Processing</b>	<b>67</b>
3.1	Introduction	67
3.2	Properties of Digital Remote Sensing Data	67
3.2.1	Digital Data	67
3.2.2	Data Formats	74
3.2.3	System Processing	78
3.3	Numerical Analysis and Software Accuracy	80
3.4	Some Remarks on Statistics	83
3.5	Summary	84
<b>4</b>	<b>Preprocessing of Remotely-Sensed Data</b>	<b>87</b>
4.1	Introduction	87
4.2	Cosmetic Operations	89
4.2.1	Missing Scan Lines	89
4.2.2	Destriping Methods	90
4.3	Geometric Correction and Registration	94
4.3.1	Orbital Geometry Model	96
4.3.2	Transformation Based on Ground Control Points	98
4.3.3	Resampling Procedures	108
4.3.4	Image Registration	111
4.3.5	Other Geometric Correction Methods	111
4.4	Atmospheric Correction	112
4.4.1	Background	112
4.4.2	Image-Based Methods	114
4.4.3	Radiative Transfer Models	115
4.4.4	Empirical Line Method	115
4.5	Illumination and View Angle Effects	116
4.6	Sensor Calibration	117
4.7	Terrain Effects	121
4.8	Summary	123
<b>5</b>	<b>Image Enhancement Techniques</b>	<b>125</b>
5.1	Introduction	125
5.2	Human Visual System	126
5.3	Contrast Enhancement	128
5.3.1	Linear Contrast Stretch	128
5.3.2	Histogram Equalization	129
5.3.3	Gaussian Stretch	138
5.4	Pseudocolour Enhancement	140
5.4.1	Density Slicing	140
5.4.2	Pseudocolour Transform	144
5.5	Summary	145
<b>6</b>	<b>Image Transforms</b>	<b>147</b>
6.1	Introduction	147
6.2	Arithmetic Operations	148
6.2.1	Image Addition	148
6.2.2	Image Subtraction	149
6.2.3	Image Multiplication	150
6.2.4	Image Division and Vegetation Indices	152
6.3	Empirically Based Image Transforms	156
6.3.1	Perpendicular Vegetation Index	156
6.3.2	Tasselled Cap (Kauth–Thomas) Transformation	157



6.4	Principal Components Analysis	160
6.4.1	Standard Principal Components Analysis	160
6.4.2	Noise-Adjusted PCA	168
6.4.3	Decorrelation Stretch	169
6.5	Hue-Saturation-Intensity (HSI) Transform	171
6.6	The Discrete Fourier Transform	172
6.6.1	Introduction	172
6.6.2	Two-Dimensional Fourier Transform	173
6.6.3	Applications of the Fourier Transform	178
6.7	The Discrete Wavelet Transform	178
6.7.1	Introduction	178
6.7.2	The One-Dimensional Discrete Wavelet Transform	179
6.7.3	The Two-Dimensional Discrete Wavelet Transform	186
6.8	Change Detection	187
6.8.1	Introduction	187
6.8.2	NDVI Difference Image	188
6.8.3	PCA	188
6.8.4	Canonical Correlation Change Analysis	192
6.8.5	Summary	195
6.9	Image Fusion	196
6.9.1	Introduction	196
6.9.2	HSI Algorithm	198
6.9.3	PCA	198
6.9.4	Gram-Schmidt Orthogonalization	198
6.9.5	Wavelet-Based Methods	198
6.9.6	Evaluation – Subjective Methods	199
6.9.7	Evaluation – Objective Methods	200
6.10	Summary	202
<b>7</b>	<b>Filtering Techniques</b>	<b>203</b>
7.1	Introduction	203
7.2	Spatial Domain Low-Pass (Smoothing) Filters	204
7.2.1	Moving Average Filter	204
7.2.2	Median Filter	208
7.2.3	Adaptive Filters	209
7.3	Spatial Domain High-Pass (Sharpening) Filters	214
7.3.1	Image Subtraction Method	214
7.3.2	Derivative-Based Methods	215
7.4	Spatial Domain Edge Detectors	219
7.5	Frequency Domain Filters	221
7.6	Summary	227
<b>8</b>	<b>Classification</b>	<b>229</b>
8.1	Introduction	229
8.2	Geometrical Basis of Classification	231
8.3	Unsupervised Classification	233
8.3.1	The $k$ -Means Algorithm	233
8.3.2	ISODATA	234
8.3.3	A Modified $k$ -Means Algorithm	239
8.4	Supervised Classification	240
8.4.1	Training Samples	240
8.4.2	Statistical Classifiers	245
8.4.3	Neural Classifiers	250

8.5	Subpixel Classification Techniques	254
8.5.1	The Linear Mixture Model	258
8.5.2	Spectral Angle Mapping	263
8.5.3	ICA	265
8.5.4	Fuzzy Classifiers	265
8.6	More Advanced Approaches to Image Classification	267
8.6.1	Support Vector Machines	267
8.6.2	Decision Trees	269
8.6.3	Other Methods of Classification	270
8.7	Incorporation of Non-spectral Features	272
8.7.1	Texture	272
8.7.2	Use of External Data	275
8.8	Contextual Information	276
8.9	Feature Selection	277
8.10	Classification Accuracy	280
8.11	Summary	283
<b>9</b>	<b>Advanced Topics</b>	<b>285</b>
9.1	Introduction	285
9.2	SAR Interferometry	285
9.2.1	Basic Principles	285
9.2.2	Interferometric Processing	290
9.2.3	Problems in SAR Interferometry	292
9.2.4	Applications of SAR Interferometry	293
9.3	Imaging Spectroscopy	294
9.3.1	Introduction	294
9.3.2	Processing Imaging Spectroscopy Data	300
9.4	Lidar	315
9.4.1	Introduction	315
9.4.2	Lidar Details	318
9.4.3	Lidar Applications	321
9.5	Summary	323
<b>10</b>	<b>Environmental Geographical Information Systems: A Remote Sensing Perspective</b>	<b>325</b>
10.1	Introduction	325
10.1.1	Definitions	326
10.1.2	The Synergy between Remote Sensing and GIS	327
10.2	Data Models, Data Structures and File Formats	328
10.2.1	Spatial Data Models	328
10.2.2	Data Structures	329
10.2.3	File Formats	331
10.2.4	Raster to Vector and Vector to Raster Conversion	331
10.3	Geodata Processing	332
10.3.1	Buffering	332
10.3.2	Overlay	332
10.4	Locational Analysis	333
10.4.1	Slope and Aspect	333
10.4.2	Proximity Analysis	334
10.4.3	Contiguity and Connectivity	334
10.5	Spatial Analysis	335
10.5.1	Point Patterns and Interpolation	335
10.5.2	Relating Field and Remotely-Sensed Measurements: Statistical Analysis	337
10.5.3	Exploratory Data Analysis and Data Mining	338

10.6	Environmental Modelling	338
10.7	Visualization	340
10.8	Multicriteria Decision Analysis of Groundwater Recharge Zones	345
10.8.1	Introduction	345
10.8.2	Data Characteristics	346
10.8.3	Multicriteria Decision Analysis	351
10.8.4	Evaluation	352
10.8.5	Conclusions	352
10.9	Assessing Flash Flood Hazards by Classifying Wadi Deposits in Arid Environments	355
10.9.1	Introduction	355
10.9.2	Water Resources in Arid Lands	355
10.9.3	Case Study from the Sinai Peninsula, Egypt	356
10.9.4	Optical and Microwave Data Fusion	357
10.9.5	Classification of Wadi Deposits	360
10.9.6	Correlation of Classification Results with Geology and Terrain Data	360
10.9.7	Conclusions	365
10.10	Remote Sensing and GIS in Archaeological Studies	365
10.10.1	Introduction	365
10.10.2	Homul (Guatemala) Case Study	365
10.10.3	Aksum (Ethiopia) Case Study	371
10.10.4	Conclusions	374
<b>Appendix A</b>	<b>Accessing MIPS</b>	<b>377</b>
<b>Appendix B</b>	<b>Getting Started with MIPS</b>	<b>379</b>
<b>Appendix C</b>	<b>Description of Sample Image Datasets</b>	<b>381</b>
<b>Appendix D</b>	<b>Acronyms and Abbreviations</b>	<b>385</b>
<b>References</b>		<b>389</b>
<b>Index</b>		<b>429</b>



# Preface to the First Edition

Environmental remote sensing is the measurement, from a distance, of the spectral features of the Earth's surface and atmosphere. These measurements are normally made by instruments carried by satellites or aircraft, and are used to infer the nature and characteristics of the land or sea surface, or of the atmosphere, at the time of observation. The successful application of remote sensing techniques to particular problems, whether they be geographical, geological, oceanographic or cartographic, requires knowledge and skills drawn from several areas of science. An understanding of the way in which remotely sensed data are acquired by a sensor mounted onboard an aircraft or satellite needs a basic knowledge of the physics involved, in particular environmental physics and optics. The use of remotely-sensed data, which are inherently digital, demands a degree of mathematical and statistical skill plus some familiarity with digital computers and their operation. A high level of competence in the field in which the remotely-sensed data are to be used is essential if full use of the information contained in those data is to be made. The term 'remote-sensing specialist' is thus, apparently, a contradiction in terms for a remote-sensing scientist must possess a broad range of expertise across a variety of disciplines. While it is, of course, possible to specialise in some particular aspect of remote sensing, it is difficult to cut oneself off from the essential multidisciplinary nature of the subject.

This book is concerned with one specialised area of remote sensing, that of digital image processing of remotely sensed data but, as we have seen, this topic cannot be treated in isolation and so Chapter 1 covers in an introductory fashion the physical principles of remote sensing. Satellite platforms currently or recently in use, as well as those proposed for the near future, are described in Chapter 2, which also contains a description of the nature and sources of remotely sensed data. The characteristics of digital computers as they relate to the processing of remotely-sensed image data is the subject of Chapter 3. The remaining five chapters cover particular topics within the general field of the processing of remotely-sensed data in the form of digital images, and their application to a range of problems drawn from the Earth and environmental sciences. Chapters 1–3 can

be considered to form the introduction to the material treated in later chapters.

The audience for this book is perceived as consisting of undergraduates taking advanced options in remote sensing in universities and colleges as part of a first degree course in geography, geology, botany, environmental science, civil engineering or agricultural science, together with postgraduate students following taught Masters courses in remote sensing. In addition, postgraduate research students and other research workers whose studies involve the use of remotely-sensed images can use this book as an introduction to the digital processing of such data. Readers whose main scientific interests lie elsewhere might find here a general survey of this relatively new and rapidly-developing area of science and technology. The nature of the intended audience requires that the formal presentation is kept to a level that is intelligible to those who do not have the benefit of a degree in mathematics, physics, computer science or engineering. This is not a research monograph, complete in every detail and pushing out to the frontiers of knowledge. Rather, it is a relatively gentle introduction to a subject which can, at first sight, appear to be overwhelming to those lacking mathematical sophistication, statistical cunning or computational genius. As such it relies to some extent on verbal rather than numerical expression of ideas and concepts. The author's intention is to provide the foundations upon which readers may build their knowledge of the more complex and detailed aspects of the use of remote-sensing techniques in their own subject rather than add to the already extensive literature which caters for a mathematically-orientated readership. Because of the multidisciplinary nature of the intended audience, and since the book is primarily concerned with techniques, the examples have been kept simple, and do not assume any specialist knowledge of geology, ecology, oceanography or other branch of Earth science. It is expected that the reader is capable of working out potential applications in his or her own field, or of following up the references given here.

It is assumed that most readers will have access to a digital image processing system, either within their own department or institution, or at a regional or national

remote sensing centre. Such processors normally have a built-in software package containing programs to carry out most, if not all, of the operations described in this book. It is hoped that the material presented here will provide such readers with the background necessary to make sensible use of the facilities at their disposal. Enough detail is provided, however, to allow interested readers to develop computer programs to implement their own ideas or to modify the operation of a standard package. Such ventures are to be encouraged, for software skills are an important part of the remote sensing scientist's training. Furthermore, the development and testing of individual ideas and conjectures provides the opportunity for experiment and innovation, which is to be preferred to the routine use of available software. It is my contention that solutions to problems are not always to be found in the user manual of a standard software package.

I owe a great deal to many people who have helped or encouraged me in the writing of this book. Michael Coombes of John Wiley & Sons, Ltd. took the risk of asking me to embark upon the venture, and has proved a reliable and sympathetic source of guidance as well as a model of patience. The Geography Department, University of Nottingham, kindly allowed me to use the facilities of the Remote Sensing Unit. I am grateful also to Jim Cahill for many helpful comments on early drafts, to Michael Steven for reading part of Chapter 1 and for providing advice on some diagrams, and to Sally Ashford for giving a student's view and to George Korybut-Daszkiewicz for his assistance with some of the photography. An anonymous referee made many

useful suggestions. My children deserve a mention (my evenings on the word-processor robbed them of the chance to play their favourite computer games) as does my wife for tolerating me. The contribution of the University of Nottingham and the Shell Exploration and Development Company to the replacement of an ageing PDP11 computer by a VAX 11/730-based image processing system allowed the continuation of remote sensing activities in the university and, consequently, the successful completion of this book. Many of the ideas presented here are the result of the development of the image processing software system now in use at the University of Nottingham and the teaching of advanced undergraduate and Masters degree courses. I am also grateful to Mr J. Winn, Chief Technician, Mr. C. Lewis and Miss E. Watts, Cartographic Unit and Mr M.A. Evans, Photographic Unit, Geography Department, University of Nottingham, for their invaluable and always friendly assistance in the production of the photographs and diagrams. None of those mentioned can be held responsible for any errors or misrepresentations that might be present in this book; it is the author's prerogative to accept liability for these.

Paul M. Mather,  
March 1987  
Remote Sensing Unit,  
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The University of Nottingham,  
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## Preface to the Second Edition

Many things have changed since the first edition of this book was written, more than 10 years ago. The increasing emphasis on scientific rigour in remote sensing (or Earth observation by remote sensing, as it is now known), the rise of interest in global monitoring and large-scale climate modelling, the increasing number of satellite-borne sensors in orbit, the development of Geographical Information Systems (GISs) technology, and the expansion in the number of taught Masters courses in GIS and remote sensing are all noteworthy developments. Perhaps the most significant single change in the world of remote sensing over the past decade has been the rapid increase in and the significantly reduced cost of computing power and software available to students and researchers alike, which allows them to deal with growing volumes of data and more sophisticated and demanding processing tools. In 1987 the level of computing power available to researchers was minute in comparison with that which is readily available today. I wrote the first edition of this book using a BBC Model B computer, which had 32 kb of memory, 100 kb diskettes and a processor which would barely run a modern refrigerator. Now I am using a 266 MHz Pentium II with 64 Mb of memory and a 2.1 Gb disk. It has a word processor that corrects my spelling mistakes (though its grammar checking can be infuriating). I can connect from my home to the University of Nottingham computers by fibre optic cable and run advanced software packages. The cost of this computer is about 1% of that of the VAX 11/730 that is mentioned in the preface to the first edition of this book.

Although the basic structure of the book remains largely unaltered, I have taken the opportunity to revise all of the chapters to bring them up to date, as well as to add some new material, to delete obsolescent and uninteresting paragraphs, and to revise some infelicitous and unintelligible passages. For example, Chapter 4 now contains new sections covering sensor calibration, plus radiometric and topographic correction. The use of artificial neural networks in image classification has grown considerably in the years since 1987, and a new section on this topic is added to Chapter 8, which also covers other recent developments in pattern recognition

and methods of estimating Earth surface properties. Chapter 3, which provides a survey of computer hardware and software, has been almost completely re-written. In Chapter 2 I have tried to give a brief overview of a range of present and past sensor systems but have not attempted to give a full summary of every sensor, because details of new developments are now readily available via the Internet. I doubt whether anyone would read this book simply because of its coverage of details of individual sensors.

Other chapters are less significantly affected by recent research as they are concerned with the basics of image processing (filtering, enhancement and image transforms), details of which have not changed much since 1987, though I have added new references and attempted to improve the presentation. I have, however, resisted the temptation to write a new chapter on GIS, largely because there are several good books on this topic that are widely accessible (for example Bonham-Carter (1994) and McGuire *et al.* (1991)), but also because I feel that this book is primarily about image processing. The addition of a chapter on GIS would neither do justice to that subject nor enhance the reader's understanding of digital processing techniques. However, I have made reference to GIS and spatial databases at a number of appropriate points in the text. My omission of a survey of GIS techniques does not imply that I consider digital image processing to be a 'stand-alone' topic. Clearly, there are significant benefits to be derived from the use of spatial data of all kinds within an integrated environment, and this point is emphasized in a number of places in this book. I have added a significant number of new references to each of the chapters, in the hope that readers might be encouraged to enjoy the comforts of his or her local library.

I have added a number of 'self-assessment' questions at the end of each chapter. These questions are not intended to constitute a sample examination paper, nor do they provide a checklist of 'important' topics (the implication being that the other topics covered in the book are unimportant). They are simply a random set of questions – if you can answer them then you probably understand the



contents of the chapter. Readers should use the Mather's Image Processing System (MIPS) software described in Appendices A and B to try out the methods mentioned in these questions. Data sets are also available on the accompanying CD, and are described in Appendix C.

Perhaps the most significant innovation that this book offers is the provision of a CD containing software and images. I am not a mathematician, and so I learn by trying out ideas rather than exclusively by reading or listening. I learn new methods by writing computer programs and applying them to various data sets. I am including a small selection of the many programs that I have produced over the past 30 years, in the hope that others may find them useful. These programs are described in Appendix B. I have been teaching a course on remote sensing for the last 14 years. When this course began there were no software packages available, so I wrote my own (my students will remember NIPS, the Nottingham Image Processing System, with varying degrees of hostility). I have completely re-written and extended NIPS so that it now runs under Microsoft Windows 95. I have renamed it to MIPS, which is rather an unimaginative name, but is nevertheless pithy. It is described in Appendix A. Many of the procedures described in this book are implemented in MIPS, and I encourage readers to try out the methods discussed in each chapter. It is only by experimenting with these methods, using a range of images, that you will learn how they work in practice. MIPS was developed on an old 486-based machine with 12 Mb of RAM and a 200 Mb disk, so it should run on most PCs available in today's impoverished universities and colleges. MIPS is not a commercial system, and should be used only for familiarisation before the reader moves on to the software behemoths that are so readily available for both PCs and UNIX workstations. Comments and suggestions for improving MIPS are welcome (preferably by email) though I warn readers that I cannot offer an advisory service nor assist in research planning!

Appendix C contains a number of Landsat, SPOT, AVHRR and RADARSAT images, mainly extracts of size 512 512 pixels. I am grateful to the copyright owners for permission to use these data sets. The images can be used by the reader to gain practical knowledge and experience of image processing operations. Many university libraries contain map collections, and I have given sufficient details of each image to allow the reader to locate appropriate maps and other back-up material that will help in the interpretation of the features shown on the images.

The audience for this book is seen to be advanced undergraduate and Masters students, as was the case in 1987. It is very easy to forget that today's student of

remote sensing and image processing is starting from the same level of background knowledge as his or her predecessors in the 1980s. Consequently, I have tried to restrain myself from including details of every technique that is mentioned in the literature. This is not a research monograph or a literature survey, nor is it primarily an exercise in self-indulgence and so some restriction on the level and scope of the coverage provided is essential if the reader is not to be overwhelmed with detail and thus discouraged from investigating further. Nevertheless, I have tried to provide references on more advanced subjects for the interested reader to follow up. The volume of published material in the field of remote sensing is now very considerable, and a full survey of the literature of the last 20 years or so would be both unrewarding and tedious. In any case, online searches of library catalogues and databases are now available from networked computers. Readers should, however, note that this book provides them only with a background introduction – successful project work will require a few visits to the library to peruse recent publications, as well as practical experience of image processing.

I am most grateful for comments from readers, a number of whom have written to me, mainly to offer useful suggestions. The new edition has, I hope, benefited from these ideas. Over the past years, I have been fortunate enough to act as supervisor to a number of postgraduate research students from various countries around the world. Their enthusiasm and commitment to research have always been a factor in maintaining my own level of interest, and I take this opportunity to express my gratitude to all of them. My friends and colleagues in the Remote Sensing Society, especially Jim Young, Robin Vaughan, Arthur Cracknell, Don Hardy and Karen Korzeniewski, have always been helpful and supportive. Discussions with many people, including Mike Barnsley, Giles Foody and Robert Gurney, have added to my knowledge and awareness of key issues in remote sensing. I also acknowledge with gratitude the help given by Dr Magaly Koch, Remote Sensing Center, Boston University, who has tested several of the procedures reported in this book and included on the CD. Her careful and thoughtful advice, support and encouragement have kept me from straying too far from reality on many occasions. My colleagues in the School of Geography in the University of Nottingham continue to provide a friendly and productive working environment, and have been known occasionally to laugh at some of my jokes. Thanks especially to Chris Lewis and Elaine Watts for helping to sort out the diagrams for the new edition, and to Dee Omar for his patient assistance and support. Michael McCullagh has been very helpful,



and has provided a lot of invaluable assistance. The staff of John Wiley & Sons has been extremely supportive, as always. Finally, my wife Rosalind deserves considerable credit for the production of this book, as she has quietly undertaken many of the tasks that, in fairness, I should have carried out during the many evenings and weekends that I have spent in front of the computer. Moreover, she has never complained about the chaotic state of our

dining room, nor about the intrusive sound of Wagner's music dramas. There are many people, in many places, who have helped or assisted me; it is impossible to name all of them, but I am nevertheless grateful. Naturally, I take full responsibility for all errors and omissions.

Paul M. Mather  
Nottingham, June 1998



## Preface to the Third Edition

In the summer of 2001 I was asked by Lyn Roberts of John Wiley & Sons, Ltd. to prepare a new edition of this book. Only minor updates would be needed, I was told, so I agreed. A few weeks later was presented with the results of a survey of the opinions of the 'great and the good' as to what should be included in and what should be excluded from the new edition. You are holding the result in your hands. The 'minor updates' turned into two new chapters (a short one on computer basics, replacing the old Chapter 3, and a lengthier one on the advanced topics of interferometry, imaging spectroscopy and lidar, making a new Chapter 9) plus substantial revisions of the other chapters. In addition, I felt that development of the MIPS software would be valuable to readers who did not have access to commercial remote sensing systems. Again, I responded to requests from postgraduate students to include various modules that they considered essential, and the result is a Windows-based package of 90 000+ lines of code.

Despite these updates and extensions both to the text of the book and the accompanying software, my target audience is still the advanced undergraduate taking a course in environmental remote sensing. I have tried to introduce each topic at a level that is accessible to the reader who is just becoming aware of the delights of image processing while, at the same time, making the reasonable assumption that my readers are, typically, enthusiastic, aware and intelligent, and wish to go beyond the basics. In order to accommodate this desire to read widely, I have included an extensive reference list. I am aware, too, that this book is used widely by students taking Masters level courses. Some of the more advanced material, for example in Chapters 6, 8 and 9, is meant for them; for example the new material on wavelets and developments in principal components analysis may stimulate Masters students to explore these new methods in their dissertation work. The first three chapters should provide a basic introduction to the background of remote sensing and image processing; Chapters 4–8 introduce essential ideas (noting the remark above concerning parts of Chapters 6 and 8), while Chapter 9 is really for the postgraduate or the specialist undergraduate.

I am a firm believer in learning by doing. Reading is not a complete substitute for practical experience of

the use of image processing techniques applied to real data that relates to real problems. For most people, interest lies in the meaning of the results of an operation in terms of the information that is conveyed about a problem rather than in probing the more arcane details of particular methods, though for others it is the techniques themselves that fascinate. The level of mathematical explanation has therefore been kept to a minimum and I have attempted to use an approach involving examples, metaphors and verbal explanation. In particular, I have introduced a number of examples, separate from the main text, which should help the reader to interpret image-processing techniques in terms of real-world applications.

Many of these examples make use of the MIPS software that is provided on the CD that accompanies this book. MIPS has grown somewhat since 1999, when the second edition of this book was published. It has a new user interface, and is able to handle images of any size in 8-, 16- or 32-bit representation. A number of new features have been added, and it is now capable of providing access to many of the techniques discussed in this book. I would appreciate reports from readers of any difficulties they experience with MIPS, and I will maintain a web site from which updates and corrections can be downloaded. The URL of this web site, and my email address, can be found in the file `contactme.txt` which is located in the root directory of the CD.

Many of the ideas in this book have come from my postgraduate students. Over the past few years, I have supervised a number of outstanding research students, whose work has kept me up to date with new developments. In particular, I would like to thank Carlos Vieira, Brandt Tso, Taskin Kavzoglu, Premelatha Balan, Mahesh Pal, Juazir Hamid, Halmi Kamarrudin and Helmi Shafri for their tolerance and good nature. Students attending my Masters classes in digital image processing have also provided frank and valuable feedback. I would also like to acknowledge the valuable assistance provided by Rosemary Hoole and Karen Laughton of the School of Geography, University of Nottingham. The help of Dr Koch of Boston University, who made many useful comments on the manuscript and the MIPS software as they have progressed, is also gratefully acknowledged, as is the kindness of Professor J. Gumuzzio and his group at the

Autonomous University of Madrid in allowing me access to DAIS images of their La Mancha study site. The DAIS data were recorded by DLR in the frame of the EC funded programme 'Access to Research Infrastructures', project 'DAIS/ROSI – Imaging Spectrometers at DLR', Co. Ro. HPRI-CT-1999-0075. Dr Koch has also provided a set of four advanced examples, which can be found in the **Examples** folder of the accompanying CD. I am very grateful to her for this contribution, which I am sure significantly enhances the value of the book. My wife continues to tolerate what she quietly considers to be my over-ambitious literary activities, as well as my predilection for the very loudest bits of Mahler, Berlioz, Wagner and others. Colleagues and students of the School

of Geography, University of Nottingham, have helped in many ways, not least by humouring me. Finally, I would like to thank Lyn Roberts, Kiely Larkins, and the staff of John Wiley who have helped to make this third edition a reality, and showed infinite patience and tolerance.

A book without errors is either trivial or guided by a divine hand. I can't believe that this book is in the latter category, and it is possible that it isn't in the former. I hope that the errors that you do find, for which I take full responsibility, are not too serious and that you will report them to me.

Paul M. Mather  
Nottingham, August 2003

# Preface to the Fourth Edition

Almost 25 years have passed since the publication of the first edition of this book. Back in 1987, image processing and geographical information systems (GIS) required dedicated computers that lived in air-conditioned rooms. At that time, I had access to a VAX 11/730, which had about the same computing power as a mobile phone of today. We had four megabytes of RAM and it took 12 hours to carry out a maximum likelihood classification on a  $512 \times 512$  Landsat four-band MSS image. Imagery with the highest multispectral spatial resolution (20 m) was acquired by the SPOT-1 satellite, and there was not a great deal of software to process it. In those days an ability to write your own programmes was essential.

Over those 25 years, new companies, new products and new applications have come into being. Integrated software packages running on fast desktop machines, processing data that may have up to 256 bands, or a spatial resolution of 50 cm, with stereo capability for DEM production, are all seen as a natural if rapid development over the period 1987–2010. Yet the basic principles of image processing remain the same, and so does the structure of this book. However, a new chapter, number ten, has been added. It covers the topic of Environmental Geographical Information Systems and Remote Sensing. I wrote in the preface to the second edition (1999) that I had resisted the temptation to include a chapter on GIS because there were several good GIS texts already available. However, developments in the fields of image processing and GIS mean that nowadays no environmental remote sensing course is complete without some reference to environmental GIS, and no environmental GIS course can be considered adequate without a discussion of the uses of remotely sensed data. In fact, over the past two or three years there has been a ‘coming together’ of GIS, remote sensing and photogrammetry. Nowadays most software vendors describe their products not as ‘Image Processing for Remote Sensing’ but as geospatial, integrated, and so on. They can interact with GIS either directly or through a common data format. This book has, therefore, to include material on GIS from a remote sensing point of view. Being aware of my inadequacies in the field of GIS, I asked Dr Magaly Koch of Boston University’s Centre for Remote Sensing to help with the new Chapter 10 and with other chapters, as she

has the benefit of considerable practical experience in the areas of remote sensing and GIS. I am very grateful to her for accepting this invitation and for making a valuable contribution to the book as a whole.

Perhaps the most important change in the appearance of the book is the introduction of colour illustrations and tables. This development is of tremendous value in a book on image processing. The use of colour supplements is a half-way house, and I always found it more trouble than it was worth. I am grateful to the publishers, and in particular to Fiona Woods, for negotiating a new full colour edition. In retrospect, trying to describe the effects of, for example, a decorrelation stretch while using only greyscale illustrations would have been a challenge to any of the great literary figures of the past, and I am sure that my powers of descriptive writing are but a shadow of theirs.

As far as other changes are concerned, I have rewritten most of Chapter 3. In the third edition Chapter 3 described the workings of the MIPS software package, which was included on a CD that accompanied the book. MIPS is still available, and can now be downloaded from the publisher’s web site ([www.wiley.com/go/mather4](http://www.wiley.com/go/mather4)). Chapter 3 now deals with aspects of computing and statistics which should be appreciated and understood by all users of computers. In particular, I feel strongly that users of remote sensing and GIS software packages should have a good understanding of the way their favoured package handles data; many people have been surprised to find that sometimes software does not always do what it says on the box. In comparison, economists and computer scientists have tested spreadsheet software such as Excel almost to destruction (McCullough, 1998, 1999). It is particularly important for the user to be aware of the nature and type of data being processed, as 8-, 10-, 12- and 16-bit data values are now in widespread use. Yet most graphics cards still limit displayed data to 8 bits per primary colour (red, green and blue) and the way that data are converted from their original format (8-, 10-, 11- or 16-bit) to fit the requirements of the graphics hardware is a matter of considerable interest, as the appearance of the image depends to a greater or lesser extent on this conversion process.

Other topics that are new to the fourth edition (apart from Chapters 3 and 10) include: updated information on new satellites and sensors (Chapter 2), new sections on change detection, and image fusion (Chapter 6), a description of the Frost filter (Chapter 7), a new section on independent components analysis (Chapter 8) plus descriptions of recent developments in image classification (support vector machines and decision trees, object-oriented classification and bagging and boosting). Other chapters have been updated, with old references removed and replaced by new ones, though several key papers from the 1970s to 1980s remain in the bibliography where they provide a uniquely intelligible description of a specific topic.

Some may query the size of the bibliography. However, modern bachelors' and Masters' programmes are more focused on assessed project work than was the case in the 1980s, and the key papers in the recent literature are catalogued in the following pages in order to provide guidance to students who are undertaking projects. I have tried to ensure that most journal paper references postdate 1994, because many electronically accessible journals are available only from the mid-1990s on, and I know that both students and researchers like to read their favourite journals online at their desk. The importance of wide reading of original papers should not be underestimated; relying solely on textbooks is not a good idea.

I have already noted that the MIPS software can be downloaded from [www.wiley.com/go/mather4](http://www.wiley.com/go/mather4). That web site also contains compressed files of PowerPoint figures and tables which can be downloaded by lecturers and teachers. These files, one for each chapter, are compressed using the popular zip method. The four case studies included on the CD that accompanied the third edition of this book are also available on the web site as pdf files (with accompanying data sets).

I would like to acknowledge the help I have received from Rachel Ballard, Fiona Woods, Izzy Canning and Sarah Karim of John Wiley & Sons, Ltd. and Gayatri Shanker of Laserwords, who have looked after me during the production of this book with great patience and forbearance. Special thanks go to Alison Woodhouse, who copy-edited the manuscript in a masterly way. I must also thank my wife, who has been a great support over the past few years while the 'book project' was developing and before. My son James helped enormously in converting diagrams to colour. There are many other people who have had an input into the writing and production of this book, ranging from librarians to graphics designers and copy editors. I thank all of them for their assistance. Finally, a note to the reader: remote sensing is a captivating and intellectually demanding subject, but it is also fun. I have enjoyed teaching and researching in remote sensing for the best part of 30 years and I hope that my

enjoyment of and enthusiasm for the subject comes across in the text and maybe inspires you to take a keen interest in whatever aspect of the subject that you are studying.

Needless to say, I take full responsibility for any errors that may be found in the book. I would be grateful if readers could advise me by email of any such errors or misrepresentations. My current email address can be found in the Contacts link on the book's web page.

Paul M. Mather  
Nottingham, January, 2010.

In the last decade, technological advances have led to a seemingly overwhelming amount of Earth observation information acquired at increasingly finer spatial, spectral and temporal scales. At the same time data processing and assimilation systems are continuously offering new and innovative ways of capturing, processing and delivering almost in real time this steady stream of geospatial data to end users, who may range from expert users to the untrained person requiring higher-level or value-added image products for decision making and problem solving.

This trend in geospatial technology development has naturally closed or at least narrowed the gap between remote sensing and GIS systems. RS data can provide both image maps for background display and estimates of the characteristics or values of environmental variables. These products can most profitably be used in conjunction with other environmental data such as rainfall or geology in the context of GIS.

I am honoured to contribute a new chapter, Chapter 10, on remote sensing and GIS integration to this new edition and would like to thank Prof. Paul Mather for giving me the opportunity to do so, and for guiding me through the process of 'co-writing a book'. The new chapter draws from my experience in applying remote sensing and GIS techniques over a number of years while working on numerous research projects mainly conducted in Boston University's Center for Remote Sensing. In this respect I am very grateful to Prof. Farouk El-Baz, director of the Center, who has been my adviser and colleague for the past two decades. I would also like to acknowledge the contributions and revisions of my colleagues Dr Francisco Estrada-Belli (Boston University), Dr Michael DiBlasi (Boston University), Dr Luisa Sernicola (University of Naples 'L'Orientale') and my PhD student Mr Ahmed Gaber (Tohoku University) in the case studies included in the new chapter 10. I hope that the combination of theoretical treatment and practical application of geospatial techniques will inspire the reader to create remote sensing and GIS-based solutions to a variety of environmental problems.

Magaly Koch  
Boston, January 2010

# List of Examples

<b>Example 2.1</b>	<b>Along-Track Scanning Radiometer (ATSR)</b>	<b>40</b>
<b>Example 2.2</b>	<b>MODIS</b>	<b>44</b>
<b>Example 2.3</b>	<b>Landsat MSS</b>	<b>47</b>
<b>Example 2.4</b>	<b>Landsat ETM+</b>	<b>51</b>
<b>Example 2.5</b>	<b>SPOT-5 Supermode</b>	<b>54</b>
<b>Example 3.1</b>	<b>Reading a Landsat ETM+ Image from CD</b>	<b>76</b>
<b>Example 4.1</b>	<b>Destriping – Linear Method</b>	<b>92</b>
<b>Example 4.2</b>	<b>Orbital Geometry Model</b>	<b>100</b>
<b>Example 4.3</b>	<b>Visualizing Polynomial Surfaces</b>	<b>103</b>
<b>Example 5.1</b>	<b>Linear Contrast Stretch</b>	<b>133</b>
<b>Example 6.1</b>	<b>The Fourier Transform</b>	<b>180</b>
<b>Example 7.1</b>	<b>Moving Average Filters</b>	<b>210</b>
<b>Example 7.2</b>	<b>Frequency Domain Filtering</b>	<b>225</b>
<b>Example 8.1</b>	<b>ISODATA Unsupervised Classification</b>	<b>236</b>
<b>Example 8.2</b>	<b>Supervised Classification</b>	<b>255</b>
<b>Example 9.1</b>	<b>DAIS 7915 Imaging Spectrometer Data</b>	<b>296</b>
<b>Example 9.2</b>	<b>Savitzky–Golay Smoothing</b>	<b>305</b>
<b>Example 9.3</b>	<b>Image Denoising Using the Wavelet Transform</b>	<b>312</b>
<b>Example 9.4</b>	<b>Lidar First/Last Return</b>	<b>320</b>





'I hope that posterity will judge me kindly, not only as to the things which I have explained but also as to those which I have intentionally omitted so as to leave to others the pleasure of discovery.'

**René Descartes (1596–1660)**

'I am none the wiser, but I am much better informed.'

**Queen Victoria (1819–1901)**

**(After being addressed by Lord Rutherford on the state of modern physics)**

'Education is an admirable thing, but it is well to remember from time to time that nothing that is worth knowing can be taught.'

**Oscar Wilde (1856–1900)**



## **Web Page**

A web page is associated with this book. Follow this link:  
[www.wiley.com/go/mather4](http://www.wiley.com/go/mather4) and you will find:

1. The MIPS image processing system software, including some test images,
2. PowerPoint Slide Shows containing all the figures and tables from each chapter,
3. A set of four example applications of remote sensing and GIS, including datasets.



# 1 Remote Sensing: Basic Principles

Electromagnetic radiation is just basically mysterious.

B.K. Ridley, *Time, Space and Things*, 2nd edition.  
Cambridge University Press, Cambridge, 1984.

## 1.1 Introduction

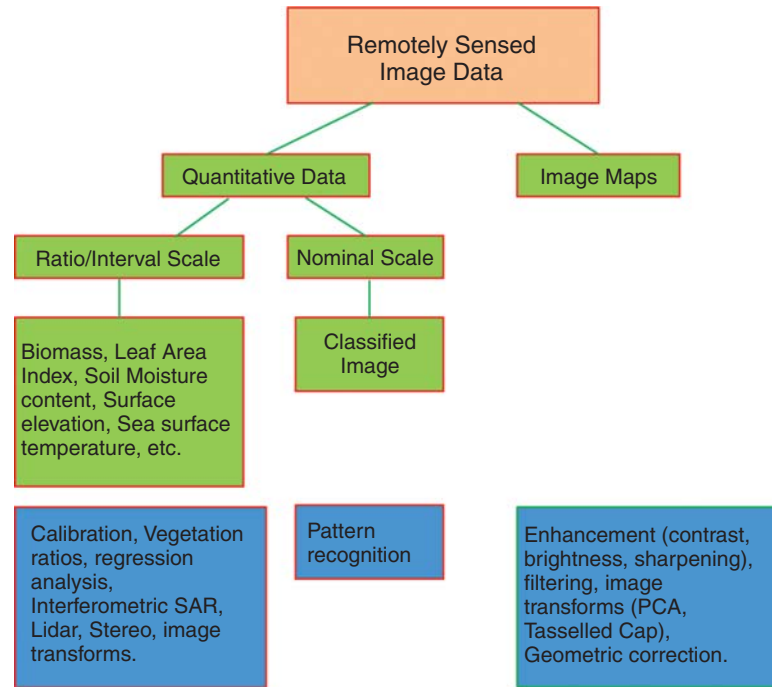
The science of remote sensing consists of the analysis and interpretation of measurements of electromagnetic radiation (EMR) that is reflected from or emitted by a target and observed or recorded from a vantage point by an observer or instrument that is not in contact with the target. Earth observation by remote sensing (EO) is the interpretation and understanding of measurements made by airborne or satellite-borne instruments of EMR that is reflected from or emitted by objects on the Earth's land, ocean or ice surfaces or within the atmosphere, together with the establishment of relationships between these measurements and the nature and distribution of phenomena on the Earth's surface or within the atmosphere. Figure 1.1 shows in schematic form the various methods of computer processing (blue boxes) that generate products (green boxes) from remotely-sensed data. This book deals with the methods of computer processing of remotely sensed data (the green and blue boxes) as well as providing an introduction to environmental geographical information systems (E-GISs) (Chapter 10) which make use of remotely-sensed products.

Remotely-sensed images are often used as image maps or backcloths for the display of spatial data in an E-GIS. Methods of improving the appearance of an image (termed *enhancement* procedures) are dealt with in Chapters 4, 5 and 7. Chapter 8 is an introduction to *pattern recognition* techniques that produce labelled images in which each type of land use, for example is represented by a numeric code (for example 1 = broadleaved forest, 2 = water, and so on.). These labelled images can provide free-standing information or can be combined with other spatial data within an E-GIS. Properties of earth surface materials, such as soil moisture content, sea

surface temperature (SST) or biomass can be related to remotely sensed measurements using statistical methods. For instance, a sample of measurements of soil moisture content can be collected close to the time of satellite overpass and the corresponding ground reflectance or ground temperature that are recorded by the satellite's instruments can be related via regression analysis to the ground measurements. This sample relationship can then be applied to the entire area of interest. These bio-geophysical variables are used in environmental modelling, often within an E-GIS. Elevation models are another form of remotely-sensed spatial information that is used in E-GIS. Digital elevation models can be derived from optical imagery using two sensors, for example one pointing down and one pointing obliquely backwards (this is the case with the ASTER sensor, discussed in Chapter 2). Another way of producing elevation models is by the use of synthetic aperture radar (SAR) interferometry, which is discussed in Chapter 9. The increasing cooperation between remote sensing specialists and E-GIS users means that more products are available to E-GIS users and the more spatial information is combined with remotely sensed data to produce improved results. This is an example of synergy (literally, working together).

A fundamental principle underlying the use of remotely sensed data is that different objects on the Earth's surface and in the atmosphere reflect, absorb, transmit or emit electromagnetic energy (EME) in different proportions across the range of wavelengths known as the electromagnetic spectrum, and that such differences allow these objects to be identified uniquely. Sensors mounted on aircraft or satellite platforms record the magnitude of the energy flux reflected from or emitted by objects on the Earth's surface. These measurements are made at a large number of points distributed either along a one-dimensional profile on the ground below the platform or over a two-dimensional area below or to one side of the ground track of the platform. Figure 1.2a shows an image being collected by a nadir-looking sensor.

Data in the form of one-dimensional profiles are not considered in this book, which is concerned with



**Figure 1.1** Uses of remotely-sensed data. The green boxes show the products derived from remotely-sensed data, such as image maps and classified images. The blue boxes show the computer processing techniques that are used to derive these products. Image maps are frequently used as backdrops in a GIS, whereas the process of pattern recognition produces labelled (nominal scale) images showing the distribution of individual Earth surface cover types. Quantitative measures such as vegetation indices are derived from calibrated data, and are often linked via regression analysis to Earth surface properties such as sea-surface temperature or soil moisture content. The computer processing techniques to extract and analyse remotely-sensed data are presented in the remainder of this book.

the processing of two-dimensional (spatial) data collected by imaging sensors. Imaging sensors are either nadir – (vertical) or side-looking. In the former case, the ground area to either side of the point immediately below the satellite or aircraft platform is imaged, while in the latter case an area of the Earth’s surface lying to one side or other of the satellite or aircraft track is imaged. The most familiar kinds of images, such as those collected by the nadir-looking thematic mapper (TM) and enhanced thematic mapper plus (ETM+) instruments carried by US Landsat satellites numbered 5 and 7 (6 never reached orbit), and by the HRV instrument (which can be side-looking or nadir-pointing) on board the French/Belgian/Swedish SPOT satellites, are scanned line by line (from side to side) as the platform moves forwards along its track. This forward (or along track) motion of the satellite or aircraft is used to build up an image of the Earth’s surface by the collection of successive scan lines (Figure 1.2a).

Two kinds of scanners are used to collect the EMR that is reflected or emitted by the ground surface along each scan line. Electromechanical scanners have a small number of detectors, and they use a mirror that moves back and forth to collect electromagnetic energy across

the width of the scan line (AB in Figure 1.2a). The electromagnetic energy reflected by or emitted from the portion of the Earth’s surface that is viewed at a given instant in time is directed by the mirror onto these detectors (Figure 1.2b). The second type of scanner, the push-broom scanner, uses an array of solid-state charge-coupled devices (CCDs), each one of which ‘sees’ a single point on the scan line (Figure 1.2c). Thus, at any given moment, each detector in the CCD array is observing a small area of the Earth’s surface along the scan line. This ground area is called a pixel. A remotely-sensed image is made up of a rectangular matrix of measurements of the flux or flow of EMR emanating from individual pixels, so that each pixel value represents the magnitude of upwelling EMR for a small ground area (though it will be seen later that there is ‘interference’ from neighbouring pixels). This upwelling radiation contains information about (i) the nature of the Earth-surface material present in the pixel area, (ii) the topographic position of the pixel area (i.e. whether it is horizontal, on a sunlit slope or on a shaded slope) and (iii) the state of the atmosphere through which the EMR has to pass. This account of image acquisition is a very simplified one, and more detail is provided in Chapter 2. The nature of Earth-surface