

Remote Sensing Digital Image Analysis

John A. Richards

Remote Sensing Digital Image Analysis

An Introduction

Fifth Edition

 Springer

John A. Richards
ANU College of Engineering and
Computer Science
The Australian National University
Canberra, ACT
Australia

ISBN 978-3-642-30061-5 ISBN 978-3-642-30062-2 (eBook)

DOI 10.1007/978-3-642-30062-2

Springer Heidelberg New York Dordrecht London

Library of Congress Control Number: 2012938702

© Springer-Verlag Berlin Heidelberg 2013

This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed. Exempted from this legal reservation are brief excerpts in connection with reviews or scholarly analysis or material supplied specifically for the purpose of being entered and executed on a computer system, for exclusive use by the purchaser of the work. Duplication of this publication or parts thereof is permitted only under the provisions of the Copyright Law of the Publisher's location, in its current version, and permission for use must always be obtained from Springer. Permissions for use may be obtained through RightsLink at the Copyright Clearance Center. Violations are liable to prosecution under the respective Copyright Law.

The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

While the advice and information in this book are believed to be true and accurate at the date of publication, neither the authors nor the editors nor the publisher can accept any legal responsibility for any errors or omissions that may be made. The publisher makes no warranty, express or implied, with respect to the material contained herein.

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

Preface

The first edition of this book appeared 25 years ago. Since then there have been enormous advances in the availability of computing resources for the analysis of remote sensing image data, and there are many more remote sensing programs and sensors now in operation. There have also been significant developments in the algorithms used for the processing and analysis of remote sensing imagery; nevertheless, many of the fundamentals have substantially remained the same. It is the purpose of this new edition to present material that has retained value since those early days, along with new techniques that can be incorporated into an operational framework for the analysis of remote sensing data.

This book is designed as a teaching text for the senior undergraduate and postgraduate student, and as a fundamental treatment for those engaged in research using digital image processing in remote sensing. The presentation level is for the mathematical non-specialist. Since the very great number of operational users of remote sensing come from the earth sciences communities, the text is pitched at a level commensurate with their background. That is important because the recognised authorities in the digital image analysis literature tend to be from engineering, computer science and mathematics. Although familiarity with a certain level of mathematics and statistics cannot be avoided, the treatment here works through analyses carefully, with a substantial degree of explanation, so that those with a minimum of mathematical preparation may still draw benefit. Appendices are included on some of the more important mathematical and statistical concepts, but a familiarity with calculus is assumed.

From an operational point of view, it is important not to separate the techniques and algorithms for image analysis from an understanding of remote sensing fundamentals. Domain knowledge guides the choice of data for analysis and allows algorithms to be selected that best suit the task at hand. Such an operational context is a hallmark of the treatment here. The coverage commences with a summary of the sources and characteristics of image data, and the reflectance and emission characteristics of earth surface materials, for those readers without a detailed knowledge of the principles and practices of remote sensing. The book

then progresses through image correction, image enhancement and image analysis, so that digital data handling is properly located in its applications domain.

While incorporating new material, decisions have been taken to omit some topics contained in earlier editions. In particular, the detailed compendium of satellite programs and sensor characteristics, included in the body of the first three editions and as an appendix in the fourth, has now been left out. There are two reasons for that. First, new satellite and aircraft missions in optical and microwave remote sensing are emerging more rapidly than the ability for a book such as this to maintain currency and, notwithstanding this, all the material is now readily obtainable through Internet sources. A detailed coverage of data compression in remote sensing has also been left out.

Another change introduced with this edition relates to referencing conventions. References are now included as footnotes rather than as end notes for each chapter, as is more common in the scientific literature. This decision was taken to make the tracking of references with the source citation simpler, and to allow the references to be annotated and commented on when they appear in the text. Nevertheless, each chapter concludes with a critical bibliography, again with comments, containing the most important material in the literature for the topics treated in that chapter. One of the implications of using footnotes is the introduction of the standard terms *ibid*, which means the reference cited immediately before, and *loc. cit.*, which means cited previously among the most recent set of footnotes.

I am indebted to a number of people for the time, ideas and data they have contributed to help bring this work to conclusion. My colleague and former student, Dr Xiuping Jia, was a co-author of the third and fourth editions, a very welcome contribution at the time when I was in management positions that left insufficient time to carry out some of the detailed work required to create those editions. On this occasion, Dr Jia's own commitments have meant that she could not participate in the project. I would like to place on record, however, my sincere appreciation of her contributions to the previous editions that have flowed through to this new version and to acknowledge the very many fruitful discussions we have had on remote sensing image analysis research over the years of our collaboration.

Dr Terry Cocks, Managing Director of HyVista Corporation Pty Ltd, Australia, very kindly made available HyMap hyperspectral imagery of Perth, Western Australia to allow many of the examples contained in this edition to be generated. Dr Larry Biehl of Purdue University was enormously patient and helpful in bringing me up to an appropriate level of expertise with MultiSpec. That is a valuable and user-friendly image analysis package that he and Professor David Landgrebe have been steadily developing over the years. It is derived from the original LARSYS system that was responsible for much digital image processing research in remote sensing carried out during the 1960s and 1970s. Their transferring that system to personal computers has brought substantial and professional processing capability within reach of any analyst and application specialist in remote sensing.

Finally, it is with a great sense of gratitude that I acknowledge the generosity of spirit of my wife Glenda for her support during the time it has taken to prepare this

new edition, and for her continued and constant support of me right through my academic career. At times, a writing task is relentless and those who contribute most are friends and family, both through encouragement and taking time out of family activities to allow the task to be brought to conclusion. I count myself very fortunate indeed.

Canberra, ACT, Australia, February 2012

John A. Richards

Contents

1	Sources and Characteristics of Remote Sensing Image Data	1
1.1	Energy Sources and Wavelength Ranges	1
1.2	Primary Data Characteristics	4
1.3	Remote Sensing Platforms	6
1.4	What Earth Surface Properties are Measured?	10
1.4.1	Sensing in the Visible and Reflected Infrared Ranges	12
1.4.2	Sensing in the Thermal Infrared Range	13
1.4.3	Sensing in the Microwave Range	15
1.5	Spatial Data Sources in General and Geographic Information Systems	18
1.6	Scale in Digital Image Data	19
1.7	Digital Earth	20
1.8	How This Book is Arranged	21
1.9	Bibliography on Sources and Characteristics of Remote Sensing Image Data	23
1.10	Problems	25
2	Correcting and Registering Images	27
2.1	Introduction	27
2.2	Sources of Radiometric Distortion	28
2.3	Instrumentation Errors	28
2.3.1	Sources of Distortion	28
2.3.2	Correcting Instrumentation Errors	30
2.4	Effect of the Solar Radiation Curve and the Atmosphere on Radiometry	31
2.5	Compensating for the Solar Radiation Curve	32
2.6	Influence of the Atmosphere	33
2.7	Effect of the Atmosphere on Remote Sensing Imagery	37

2.8	Correcting Atmospheric Effects in Broad Waveband Systems	38
2.9	Correcting Atmospheric Effects in Narrow Waveband Systems	40
2.10	Empirical, Data Driven Methods for Atmospheric Correction	44
	2.10.1 Haze Removal by Dark Subtraction	44
	2.10.2 The Flat Field Method.	45
	2.10.3 The Empirical Line Method.	45
	2.10.4 Log Residuals	46
2.11	Sources of Geometric Distortion.	47
2.12	The Effect of Earth Rotation	48
2.13	The Effect of Variations in Platform Altitude, Attitude and Velocity	50
2.14	The Effect of Sensor Field of View: Panoramic Distortion.	51
2.15	The Effect of Earth Curvature	53
2.16	Geometric Distortion Caused by Instrumentation Characteristics	54
	2.16.1 Sensor Scan Nonlinearities.	55
	2.16.2 Finite Scan Time Distortion.	55
	2.16.3 Aspect Ratio Distortion	55
2.17	Correction of Geometric Distortion.	56
2.18	Use of Mapping Functions for Image Correction	56
	2.18.1 Mapping Polynomials and the Use of Ground Control Points.	57
	2.18.2 Building a Geometrically Correct Image	58
	2.18.3 Resampling and the Need for Interpolation	59
	2.18.4 The Choice of Control Points.	61
	2.18.5 Example of Registration to a Map Grid.	62
2.19	Mathematical Representation and Correction of Geometric Distortion.	64
	2.19.1 Aspect Ratio Correction	64
	2.19.2 Earth Rotation Skew Correction	65
	2.19.3 Image Orientation to North–South	66
	2.19.4 Correcting Panoramic Effects.	66
	2.19.5 Combining the Corrections	66
2.20	Image to Image Registration	67
	2.20.1 Refining the Localisation of Control Points	67
	2.20.2 Example of Image to Image Registration.	69
2.21	Other Image Geometry Operations	71
	2.21.1 Image Rotation.	71
	2.21.2 Scale Changing and Zooming.	72

2.22	Bibliography on Correcting and Registering Images	72
2.23	Problems	73
3	Interpreting Images	79
3.1	Introduction	79
3.2	Photointerpretation	79
3.2.1	Forms of Imagery for Photointerpretation	80
3.2.2	Computer Enhancement of Imagery for Photointerpretation.	82
3.3	Quantitative Analysis: From Data to Labels.	83
3.4	Comparing Quantitative Analysis and Photointerpretation . . .	84
3.5	The Fundamentals of Quantitative Analysis	86
3.5.1	Pixel Vectors and Spectral Space	86
3.5.2	Linear Classifiers	88
3.5.3	Statistical Classifiers	90
3.6	Sub-Classes and Spectral Classes	92
3.7	Unsupervised Classification	93
3.8	Bibliography on Interpreting Images	94
3.9	Problems	95
4	Radiometric Enhancement of Images	99
4.1	Introduction	99
4.1.1	Point Operations and Look Up Tables.	99
4.1.2	Scalar and Vector Images	99
4.2	The Image Histogram	100
4.3	Contrast Modification	100
4.3.1	Histogram Modification Rule	100
4.3.2	Linear Contrast Modification	102
4.3.3	Saturating Linear Contrast Enhancement	102
4.3.4	Automatic Contrast Enhancement	103
4.3.5	Logarithmic and Exponential Contrast Enhancement	105
4.3.6	Piecewise Linear Contrast Modification.	105
4.4	Histogram Equalisation	106
4.4.1	Use of the Cumulative Histogram.	106
4.4.2	Anomalies in Histogram Equalisation	112
4.5	Histogram Matching	114
4.5.1	Principle	114
4.5.2	Image to Image Contrast Matching	115
4.5.3	Matching to a Mathematical Reference	115
4.6	Density Slicing	118
4.6.1	Black and White Density Slicing	118
4.6.2	Colour Density Slicing and Pseudocolouring	119

4.7	Bibliography on Radiometric Enhancement of Images.	120
4.8	Problems	122
5	Geometric Processing and Enhancement: Image Domain Techniques	127
5.1	Introduction	127
5.2	Neighbourhood Operations in Image Filtering	127
5.3	Image Smoothing	130
5.3.1	Mean Value Smoothing	130
5.3.2	Median Filtering	132
5.3.3	Modal Filtering.	133
5.4	Sharpening and Edge Detection	133
5.4.1	Spatial Gradient Methods.	134
5.4.1.1	The Roberts Operator	135
5.4.1.2	The Sobel Operator	136
5.4.1.3	The Prewitt Operator	136
5.4.1.4	The Laplacian Operator	137
5.4.2	Subtractive Smoothing (Unsharp Masking)	138
5.5	Edge Detection.	139
5.6	Line and Spot Detection	141
5.7	Thinning and Linking	142
5.8	Geometric Processing as a Convolution Operation	142
5.9	Image Domain Techniques Compared with Using the Fourier Transform	145
5.10	Geometric Properties of Images	146
5.10.1	Measuring Geometric Properties	146
5.10.2	Describing Texture	147
5.11	Morphological Analysis.	150
5.11.1	Erosion	152
5.11.2	Dilation	153
5.11.3	Opening and Closing.	154
5.11.4	Boundary Extraction	155
5.11.5	Other Morphological Operations.	156
5.12	Shape Recognition	157
5.13	Bibliography on Geometric Processing and Enhancement: Image Domain Techniques.	157
5.14	Problems	158
6	Spectral Domain Image Transforms	161
6.1	Introduction	161
6.2	Image Arithmetic and Vegetation Indices	162
6.3	The Principal Components Transformation	163
6.3.1	The Mean Vector and The Covariance Matrix	164
6.3.2	A Zero Correlation, Rotational Transform	167
6.3.3	The Effect of an Origin Shift	173

6.3.4	Example and Some Practical Considerations	173
6.3.5	Application of Principal Components in Image Enhancement and Display	176
6.3.6	The Taylor Method of Contrast Enhancement	178
6.3.7	Use of Principal Components for Image Compression	181
6.3.8	The Principal Components Transform in Change Detection Applications	182
6.3.9	Use of Principal Components for Feature Reduction	186
6.4	The Noise Adjusted Principal Components Transform.	186
6.5	The Kauth–Thomas Tasseled Cap Transform	189
6.6	The Kernel Principal Components Transformation	192
6.7	HSI Image Display	195
6.8	Pan Sharpening.	197
6.9	Bibliography on Spectral Domain Image Transforms	198
6.10	Problems	199
7	Spatial Domain Image Transforms	203
7.1	Introduction	203
7.2	Special Functions	204
7.2.1	The Complex Exponential Function	204
7.2.2	The Impulse or Delta Function.	206
7.2.3	The Heaviside Step Function	207
7.3	The Fourier Series	207
7.4	The Fourier Transform	210
7.5	The Discrete Fourier Transform	212
7.5.1	Properties of the Discrete Fourier Transform	214
7.5.2	Computing the Discrete Fourier Transform	215
7.6	Convolution	215
7.6.1	The Convolution Integral.	215
7.6.2	Convolution with an Impulse	216
7.6.3	The Convolution Theorem.	216
7.6.4	Discrete Convolution.	217
7.7	Sampling Theory	218
7.8	The Discrete Fourier Transform of an Image	221
7.8.1	The Transformation Equations	221
7.8.2	Evaluating the Fourier Transform of an Image.	222
7.8.3	The Concept of Spatial Frequency	223
7.8.4	Displaying the DFT of an Image	223
7.9	Image Processing Using the Fourier Transform	224
7.10	Convolution in two Dimensions	226
7.11	Other Fourier Transforms	227
7.12	Leakage and Window Functions.	227

7.13	The Wavelet Transform	229
7.13.1	Background	229
7.13.2	Orthogonal Functions and Inner Products	229
7.13.3	Wavelets as Basis Functions	230
7.13.4	Dyadic Wavelets with Compact Support	232
7.13.5	Choosing the Wavelets	232
7.13.6	Filter Banks	233
7.13.6.1	Sub Band Filtering, and Downsampling	233
7.13.6.2	Reconstruction from the Wavelets, and Upsampling	237
7.13.6.3	Relationship Between the Low and High Pass Filters	238
7.13.7	Choice of Wavelets	239
7.14	The Wavelet Transform of an Image	241
7.15	Applications of the Wavelet Transform in Remote Sensing Image Analysis	241
7.16	Bibliography on Spatial Domain Image Transforms	243
7.17	Problems	244
8	Supervised Classification Techniques	247
8.1	Introduction	247
8.2	The Essential Steps in Supervised Classification	248
8.3	Maximum Likelihood Classification	250
8.3.1	Bayes' Classification	250
8.3.2	The Maximum Likelihood Decision Rule	251
8.3.3	Multivariate Normal Class Models	252
8.3.4	Decision Surfaces	253
8.3.5	Thresholds	253
8.3.6	Number of Training Pixels Required	255
8.3.7	The Hughes Phenomenon and the Curse of Dimensionality	256
8.3.8	An Example	258
8.4	Gaussian Mixture Models	260
8.5	Minimum Distance Classification	265
8.5.1	The Case of Limited Training Data	265
8.5.2	The Discriminant Function	267
8.5.3	Decision Surfaces for the Minimum Distance Classifier	267
8.5.4	Thresholds	268
8.5.5	Degeneration of Maximum Likelihood to Minimum Distance Classification	268
8.5.6	Classification Time Comparison of the Maximum Likelihood and Minimum Distance Rules	269
8.6	Parallelepiped Classification	269

8.7	Mahalanobis Classification	271
8.8	Non-Parametric Classification	271
8.9	Table Look Up Classification	272
8.10	k NN (Nearest Neighbour) Classification	273
8.11	The Spectral Angle Mapper	274
8.12	Non-Parametric Classification from a Geometric Basis	274
	8.12.1 The Concept of a Weight Vector	274
	8.12.2 Testing Class Membership	275
8.13	Training a Linear Classifier	276
8.14	The Support Vector Machine: Linearly Separable Classes	276
8.15	The Support Vector Machine: Overlapping Classes	281
8.16	The Support Vector Machine: Nonlinearly Separable Data and Kernels	283
8.17	Multi-Category Classification with Binary Classifiers	286
8.18	Committees of Classifiers	288
	8.18.1 Bagging	288
	8.18.2 Boosting and AdaBoost	289
8.19	Networks of Classifiers: The Neural Network	290
	8.19.1 The Processing Element	291
	8.19.2 Training the Neural Network—Backpropagation	292
	8.19.3 Choosing the Network Parameters	296
	8.19.4 Example	297
8.20	Context Classification	299
	8.20.1 The Concept of Spatial Context	299
	8.20.2 Context Classification by Image Pre-processing	302
	8.20.3 Post Classification Filtering	302
	8.20.4 Probabilistic Relaxation Labelling	303
	8.20.4.1 The Algorithm	303
	8.20.4.2 The Neighbourhood Function	304
	8.20.4.3 Determining the Compatibility Coefficients	305
	8.20.4.4 Stopping the Process	306
	8.20.4.5 Examples	307
	8.20.5 Handling Spatial Context by Markov Random Fields	308
8.21	Bibliography on Supervised Classification Techniques	312
8.22	Problems	315
9	Clustering and Unsupervised Classification	319
9.1	How Clustering is Used	319
9.2	Similarity Metrics and Clustering Criteria	320
9.3	k Means Clustering	322
	9.3.1 The k Means Algorithm	322
9.4	Isodata Clustering	323

9.4.1	Merging and Deleting Clusters	323
9.4.2	Splitting Elongated Clusters	325
9.5	Choosing the Initial Cluster Centres	325
9.6	Cost of k Means and Isodata Clustering.	326
9.7	Unsupervised Classification	326
9.8	An Example of Clustering with the k Means Algorithm	327
9.9	A Single Pass Clustering Technique	327
9.9.1	The Single Pass Algorithm.	327
9.9.2	Advantages and Limitations of the Single Pass Algorithm	329
9.9.3	Strip Generation Parameter	329
9.9.4	Variations on the Single Pass Algorithm	330
9.9.5	An Example of Clustering with the Single Pass Algorithm	331
9.10	Hierarchical Clustering	331
9.10.1	Agglomerative Hierarchical Clustering	332
9.11	Other Clustering Metrics	333
9.12	Other Clustering Techniques	333
9.13	Cluster Space Classification	335
9.14	Bibliography on Clustering and Unsupervised Classification	339
9.15	Problems	340
10	Feature Reduction	343
10.1	The Need for Feature Reduction.	343
10.2	A Note on High Dimensional Data	344
10.3	Measures of Separability	345
10.4	Divergence.	345
10.4.1	Definition	345
10.4.2	Divergence of a Pair of Normal Distributions.	347
10.4.3	Using Divergence for Feature Selection.	348
10.4.4	A Problem with Divergence.	349
10.5	The Jeffries-Matusita (JM) Distance	350
10.5.1	Definition	350
10.5.2	Comparison of Divergence and JM Distance	351
10.6	Transformed Divergence	351
10.6.1	Definition	351
10.6.2	Transformed Divergence and the Probability of Correct Classification	352
10.6.3	Use of Transformed Divergence in Clustering	353
10.7	Separability Measures for Minimum Distance Classification	353
10.8	Feature Reduction by Spectral Transformation	354

10.8.1	Feature Reduction Using the Principal Components Transformation	354
10.8.2	Feature Reduction Using the Canonical Analysis Transformation	356
10.8.2.1	Within Class and Among Class Covariance	358
10.8.2.2	A Separability Measure	359
10.8.2.3	The Generalised Eigenvalue Equation	359
10.8.2.4	An Example	360
10.8.3	Discriminant Analysis Feature Extraction (DAFE)	362
10.8.4	Non-Parametric Discriminant Analysis (NDA)	364
10.8.5	Decision Boundary Feature Extraction (DBFE)	368
10.8.6	Non-Parametric Weighted Feature Extraction (NWFE)	369
10.9	Block Diagonalising the Covariance Matrix	370
10.10	Improving Covariance Estimates Through Regularisation	375
10.11	Bibliography on Feature Reduction	377
10.12	Problems	378
11	Image Classification in Practice	381
11.1	Introduction	381
11.2	An Overview of Classification	382
11.2.1	Parametric and Non-parametric Supervised Classifiers	382
11.2.2	Unsupervised Classification	383
11.2.3	Semi-Supervised Classification	384
11.3	Supervised Classification with the Maximum Likelihood Rule	384
11.3.1	Outline	384
11.3.2	Gathering Training Data	385
11.3.3	Feature Selection	386
11.3.4	Resolving Multimodal Distributions	387
11.3.5	Effect of Resampling on Classification	387
11.4	A Hybrid Supervised/Unsupervised Methodology	388
11.4.1	Outline of the Method	388
11.4.2	Choosing the Image Segments to Cluster	389
11.4.3	Rationalising the Number of Spectral Classes	390
11.4.4	An Example	390
11.5	Cluster Space Classification	393
11.6	Supervised Classification Using the Support Vector Machine	394
11.6.1	Initial Choices	394
11.6.2	Grid Searching for Parameter Determination	395
11.6.3	Data Centering and Scaling	395

11.7	Assessing Classification Accuracy	396
11.7.1	Use of a Testing Set of Pixels	396
11.7.2	The Error Matrix	397
11.7.3	Quantifying the Error Matrix	398
11.7.4	The Kappa Coefficient	401
11.7.5	Number of Testing Samples Required for Assessing Map Accuracy	405
11.7.6	Number of Testing Samples Required for Populating the Error Matrix	410
11.7.7	Placing Confidence Limits on Assessed Accuracy	412
11.7.8	Cross Validation Accuracy Assessment and the Leave One Out Method	413
11.8	Decision Tree Classifiers	413
11.8.1	CART (Classification and Regression Trees)	415
11.8.2	Random Forests	420
11.8.3	Progressive Two-Class Decision Classifier	421
11.9	Image Interpretation through Spectroscopy and Spectral Library Searching	422
11.10	End Members and Unmixing	424
11.11	Is There a Best Classifier?	426
11.12	Bibliography on Image Classification in Practice	431
11.13	Problems	433
12	Multisource Image Analysis	437
12.1	Introduction	437
12.2	Stacked Vector Analysis	438
12.3	Statistical Multisource Methods	439
12.3.1	Joint Statistical Decision Rules	439
12.3.2	Committee Classifiers	441
12.3.3	Opinion Pools and Consensus Theory	442
12.3.4	Use of Prior Probabilities	443
12.3.5	Supervised Label Relaxation	443
12.4	The Theory of Evidence	444
12.4.1	The Concept of Evidential Mass	444
12.4.2	Combining Evidence with the Orthogonal Sum	446
12.4.3	Decision Rules	448
12.5	Knowledge-Based Image Analysis	448
12.5.1	Emulating Photointerpretation to Understand Knowledge Processing	449
12.5.2	The Structure of a Knowledge-Based Image Analysis System	450
12.5.3	Representing Knowledge in a Knowledge-Based Image Analysis System	452
12.5.4	Processing Knowledge: The Inference Engine	454

12.5.5	Rules as Justifiers of a Labelling Proposition	454
12.5.6	Endorsing a Labelling Proposition	455
12.5.7	An Example.	456
12.6	Operational Multisource Analysis	458
12.7	Bibliography on Multisource Image Analysis	461
12.8	Problems	463
Appendix A: Satellite Altitudes and Periods		465
Appendix B: Binary Representation of Decimal Numbers		467
Appendix C: Essential Results from Vector and Matrix Algebra.		469
Appendix D: Some Fundamental Material from Probability and Statistics.		479
Appendix E: Penalty Function Derivation of the Maximum Likelihood Decision Rule		483
Index		487