Hyperspectral Remote Sensing

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Dedicated with love to Michelle, Maria, and Katie

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Preface

Hyperspectral imaging is an emerging field of electro-optical and infrared remote sensing. Advancements in sensing and processing technology have reached a level that allows hyperspectral imaging to be more widely applied to remote sensing problems. Because of this, I was asked roughly six years ago to serve as an adjunct faculty member at the Air Force Institute of Technology in Ohio to construct and teach a graduate course on this subject as part of their optical engineering program. As I searched for a suitable textbook from which to teach this course, it became apparent to me that there were none that provided the comprehensive treatment I felt the subject required. Hyperspectral remote sensing is a highly multidisciplinary field, and I believe that a student of this subject matter should appreciate and understand all of its major facets, including material spectroscopy, radiative transfer, imaging spectrometry, and hyperspectral data processing. There are many resources that suitably cover these areas individually, but none that are all inclusive. This book is my attempt to provide an end-to-end treatment of hyperspectral remote sensing technology.

I have been using this textbook in manuscript form to teach a one-quarter class at the graduate level, with Masters and Ph.D. students taking the course as an elective and subsequently performing their research in the hyperspectral remote sensing field. The amount of material is arguably too much to fit within a single quarter and would ideally be spread over a semester or two quarters if possible. The content of the book is oriented toward the physical principles of hyperspectral remote sensing as opposed to applications of hyperspectral technology, with the expectation that students finish the class armed with the required knowledge to become practitioners in the field; be able to understand the immense literature available in this technology area; and apply their knowledge to the understanding of material spectral properties, the design of hyperspectral systems, the analysis of hyperspectral imagery, and the application of the technology to specific problems.

There are many people I would like to thank for helping me complete this book. First, I would like to thank the Air Force Research Laboratory for their support of this endeavor, and my many colleagues in the

hyperspectral remote sensing field from whom I have drawn knowledge and inspiration during the 15 years I have performed research in this area. I would like to thank all of my OENG 647 Hyperspectral Remote Sensing students at the Air Force Institute of Technology who suffered through early versions of this manuscript and provided invaluable feedback to help improve it. In particular, I owe great thanks to Joseph Meola of the Air Force Research Laboratory, who performed a very thorough review of the manuscript, made numerous corrections and suggestions, and contributed material to Chapters 10 and 14, including participating in useful technical discussions concerning nuances of signal processing theory. I am very grateful for thorough, insightful, and constructive reviews of my original manuscript performed by Dr. John Schott of the Rochester Institute of Technology and Dr. Joseph Shaw of Montana State University on behalf of SPIE Press, as well as Tim Lamkins, Dara Burrows, and their staff at SPIE Press for turning my manuscript into an actual book. Additionally, I would like to acknowledge the support of Philip Maciejewski of the Air Force Research Laboratory for performing vegetation spectral measurements, the National Aeronautics and Space Agency (NASA) for the Hyperion data, the Defense Intelligence Agency for the HYDICE data, John Hackwell and the Aerospace Corporation for the SEBASS data, Patrick Brezonik and the University of Minnesota for the lake reflectance spectra, Joseph Shaw of Montana State University for the downwelling FTIR measurements, Bill Smith of NASA Langley Research Center for the GIFTS schematic and example data, and others acknowledged throughout this book for the courtesy of using results published in other books and journals.

Finally, this book would not have been possible were it not for the help and support of my wife Michelle and daughters Maria and Katie, who provided great patience and encouragement during the many hours that their husband and father was preparing, typing, and editing this book instead of giving time to them and attending to other things around our home. Now that this immense undertaking is completed, I hope to make up for some of what was lost.

Michael T. Eismann
Beavercreek, Ohio
March 2012

List of Acronyms

ACE	adaptive coherence/cosine estimator
ADC	analog-to-digital conversion
AHI	Airborne Hyperspectral Imager
AIRIS	Adaptive Infrared Imaging Spectroradiometer
AIS	Airborne Imaging Spectrometer
amu	atomic mass unit
AOTF	acousto-optic tunable filter
AR	antireflection (coating)
ARCHER	Airborne Real-Time Cueing Hyperspectral Enhanced Reconnaissance
ARM	Atmospheric Radiation Measurement (site)
ASD	adaptive subspace detector
ATREM	atmospheric removal program
AUC	area under (the ROC) curve
AVIRIS	Airborne Visible/Infrared Imaging Spectrometer
BI	bare-soil index
BLIP	background-limited performance
BRDF	bidirectional reflectance distribution function
CBAD	cluster-based anomaly detector
CCD	charge-coupled device
CCSMF	class-conditional spectral matched filter
CDF	cumulative distribution function
CEM	constrained energy minimization (detector)
CFAR	constant false-alarm rate
CMOS	complementary metal-oxide semiconductor
COMPASS	Compact Airborne Spectral Sensor
CSD	complementary subspace detector
CTIS	chromotomographic imaging spectrometer
DDR-SDRAM	double-data-rate synchronous dynamic random access memory
DFT	discrete Fourier transform
DHR	directional hemispherical reflectance
DIRSIG	Digital Image and Remote Sensing Image Generation
DISORT	multiple-scattering discrete-ordinate radiative transfer program for a multilayered plane-parallel medium
DN	data number
DOP	degree of polarization

ED	Euclidian distance (detector)
ELM	empirical line method
EM	expectation maximization (algorithm)
EO/IR	electro-optical and infrared
FAM	false-alarm mitigation
FAR	false-alarm rate
FCBAD	fuzzy cluster-based anomaly detector
FFT	fast Fourier transform
FIRST	Field Portable Imaging Radiometric Spectrometer Technology (spectrometer)
FLAASH	fast line-of-sight atmospheric analysis of spectral hypercubes
FOV	field of view
FPA	focal plane array
fps	frames per second
FTHSI	Fourier Transform Hyperspectral Imager
FTIR	Fourier transform infrared (spectrometer)
FTMF	finite target matched filter
FTS	Fourier transform spectrometer
FWHM	full-width at half-maximum
GIFTS	Geosynchronous Imaging Fourier Transform Spectrometer
GIQE	general image-quality equation
GLRT	generalized likelihood ratio test
GMM	Gaussian mixture model
GMRX	Gaussian mixture Reed–Xiaoli (detector)
GRD	ground-resolved distance
GSD	ground-sample distance
HDR	hemispherical directional reflectance
HICO™	Hyperspectral Imager for the Coastal Ocean
HITRAN	high-resolution transmission molecular absorption
HYDICE	Hyperspectral Digital Imagery Collection Experiment
ICA	independent component analysis
IFOV	instantaneous field of view
IS	integrating sphere
ISAC	in-scene atmospheric compensation
ISMC	improved split-and-merge clustering
ISODATA	iterative self-organizing data analysis technique
JPL	Let Propulsion Lab
JSD	joint subspace detector
kNN	*k* nearest neighbor
KS	Kolmogorov–Smirnov (test)

LARS	least-angle regression
LBG	Linde–Buzo–Gray (clustering)
LMM	linear mixing model
LOS	line of sight
LRT	likelihood ratio test
LVF	linear variable filter
LWIR	longwave infrared
MBCD	model-based change detector
MD	Mahalanobis distance
ML	maximum likelihood (algorithm)
MLE	maximum-likelihood estimate
MNF	maximum (or minimum) noise fraction
MODTRAN	moderate-resolution atmospheric transmission and radiance code
MSE	mean-squared error
MTF	modulation transfer function
MTMF	mixture-tuned matched filter
MWIR	midwave infrared
NA	numerical aperture
NAPC	noise-adjusted principal component
NCM	normal compositional model
NDVI	Normalized Differential Vegetation Index
NEI	noise-equivalent irradiance
NE*L*	noise-equivalent radiance
NEP	noise-equivalent power
NESR	noise-equivalent spectral radiance
NIIRS	Normalized Image Interpretability Rating Scale
NIR	near infrared
NIST	National Institute of Standards and Technology
NVIS	night vision imaging spectrometer
OPD	optical path difference
OPRA	oblique projection retrieval of the atmosphere
OSP	orthogonal subspace projection
PALM	pair-wise adaptive linear matched (filter)
PC	principal component
PCA	principal-component analysis
PPI™	Pixel Purity Index™
ppm	parts per million
PSF	point spread function
QSF	quadratic spectral filter
QTH	quartz tungsten

QUAC	quick atmospheric compensation
RMS	root mean square
ROC	receiver operating characteristic
ROIC	readout integrated circuit
RX	Reed–Xiaoli (detector)
SAM	spectral angle mapper
SCR	signal-to-clutter ratio
SEBASS	Spectrally Enhanced Broadband Array Spectrograph System
SEM	stochastic expectation maximization
SMF	spectral matched filter
SMIFTS	Spatially Modulated Imaging Fourier Transform Spectrometer
SMM	stochastic mixing model
SNR	signal-to-noise ratio
SRF	spectral response function
SS	subspace (detector)
SS-ACE	subspace adaptive coherence/cosine estimator
SSD	subpixel subspace detector
SSRX	subspace Reed–Xiaoli (detector)
SVD	singular-value decomposition
SVM	support vector machine
SWIR	shortwave infrared
SWIR1	short-wavelength end of the SWIR spectral region
SWIR2	long-wavelength end of the SWIR spectral region
TMA	three-mirror anastigmatic (design)
USGS	United States Geological Survey
VIS	visible
VNIR	visible and near-infrared
ZPD	zero path difference