

PREFACE

Hyperspectral imaging has witnessed tremendous growth over the past years. Its applications to new areas are still yet to explore. Many hyperspectral imaging techniques have been developed and also reported in various venues. My first book, *Hyperspectral Imaging: Techniques for Spectral Detection and Classification*, referenced as Chang (2003a), was written in an attempt to summarize the research conducted then in my laboratory, Remote Sensing Signal and Image Processing Laboratory (RSSIPL) and to provide readers with a peek of this fascinating and excited area. Amazingly, this area has advanced so rapidly that many signal processing techniques have continuously emerged and developed for hyperspectral signal and image processing since then. In order to catch up this trend, this book is written as a second book with four goals in mind. One is to continuously explore new statistical signal processing algorithms in this area for various applications. Many results in this book are new, particularly, some in Chapters 2, 4, 5-6, 11, 16, 18-19, 23, 24, 29, 30-31, 33 which have not been published at the time I am writing this book. A second goal is to supplement Chang (2003a) where many potential and yet promising research efforts were only briefly mentioned in Chapter 18 in the book but were not be able to be included at the time when Chang (2003a) was completed. A third goal is to distinguish this book from Chang (2003a) in many ways. Unlike Chang (2003a) whose main theme is hyperspectral target detection and classification from a view point of subpixel and mixed pixel analysis, this book is focused on more in-depth treatment of hyperspectral signal and image processing from a statistical signal processing's point of view. A fourth and last goal is to take up several unsettled but very important issues which have been avoided and never addressed in the past.

One is an issue of "how many spectral signatures are required to be used to unmix data?" arising in linear hyperspectral unmixing. This has been a long standing and unresolved issue in remote sensing image processing, specifically hyperspectral imaging since the number of signatures to be used for data unmixing has significant impact on image analysis while its accurate number is never known in real applications. Another is "how many pure spectral signatures, referred to as endmembers, are supposed to be present in the data to be processed?". It has been a common sense to assume that the number of signatures used for spectral unmixing is the same number of endmembers. Unfortunately, such a claim, which has been widely adopted and accepted in the community, is generally not true in practical applications (see Chapter 17). The issue of endmembers has not received much interest in multispectral image analysis because of its low spectral and spatial resolutions which generally result in mixed data sample vectors.

However, due to recent advances of hyperspectral imaging sensors with hundreds of contiguous spectral bands endmember extraction has become increasingly important since endmembers provide crucial “non-literal” information in spectral interpretation, characterization and analysis. Interestingly, this issue has never been seriously addressed until recently when it was investigated by a series of papers (Chang, 2006a; Chang 2006b; Chang and Plaza, 2006; Chang et al., 2006; Plaza and Chang 2006) by introducing a new concept of Virtual Dimensionality (VD). Besides, some controversial issues also occur resulting from misinterpreting VD. Therefore, one of major chapters in this book is Chapter 5 which revisits VD to explore its utility in various applications. Unlike the Intrinsic Dimensionality (ID), also known as Effective Dimensionality (ED), which is somewhat abstract and defined as the minimum number of parameters to represent general high-dimensional multivariate data, VD is more practical and realistic. It is defined as the number of “*spectrally*” distinct signatures and particularly developed for hyperspectral data in which the non-literal (spectral) information is more crucial and vital than information provided by other dimensions such as spatial information. Specifically, an issue arises in how to define the spectral distinction among signatures in VD estimation. Furthermore, unlike ID which is a one size-fit-all definition for all data sets, VD should adapt to data sets used for different applications as well as vary with the techniques used to estimate VD. In order to address this issue, Chapter 5 explores two types of VD criteria, data characterization-driven criteria and data representation-driven criteria to define spectrally distinct signatures and further decouples the concept of VD from the techniques used to estimate VD. Consequently, when VD is poorly estimated by one technique for a particular data set, it is not the definition of VD to take blame, but rather the technique used for VD estimation which is not applicable to this particular data set. In addition, a related issue to VD is “characterization of pixel information”. For example, an anomaly is not necessarily an endmember and vice versa. So, “what is the distinction between these two?” and “how do we characterize these two?” become interesting in hyperspectral data exploitation. This issue is addressed in Chapter 18.

Another interesting topic presented in this book is to introduce a new concept of “hyperspectral information compression” in Chapters 19-23. It is different from the commonly used so-called “hyperspectral data compression” in the sense that hyperspectral information compression is generally performed based on the information required to be retained rather than the size of hyperspectral data to be compressed. Therefore, a more appropriate term to be used is “exploitation-based lossy hyperspectral data compression”. Nevertheless, it should be noted that the definitions and terminologies introduced in these chapters are by no means standard, but rather being used by my preference.

Finally, an issue of “multispectral imagery versus hyperspectral imagery” is also investigated. It seems that there is no cut-and-dried definition to distinguish these two terminologies. A general understanding of distinction between these two is that a hyperspectral image is acquired by hundreds of *contiguous* spectral channels/bands with very high spectral resolution, while a multispectral image is collected by tens of *discrete* spectral channels/bands with low spectral resolution. If this interpretation is used, we then run into a dilemma, “how many spectral channels/bands are sufficiently enough for a remotely sensed image to be called a hyperspectral image?” or “how fine the spectral resolution should be for a remote sensing image to be qualified as a hyperspectral image?”. For example, if we take a small set of hyperspectral band images with spectral resolution 10 nm, say 5 spectral band images, to form a 5-dimensional image cube, do we

still consider this new formed 5-dimensional image cube as a hyperspectral image or simply a multispectral image? If we adopt the former definition based on the number of bands, this 5-dimensional image cube should be viewed as a multispectral image. On the other hand, if we adopt the latter definition based on spectral resolution, the 5-dimensional image cube should be considered as a hyperspectral image. Thus far, it seems that there is no general consensus to settle this issue. In Chapter 31, I make an attempt to address this issue from a view point of how two versions of Independent Component Analysis (ICA), over-complete ICA and under-complete ICA, can be used to resolve this long debating issue in the context of Linear Spectral Mixture Analysis (LSMA). After all, some of these issues may never be settled or standardized for years to come. Many researchers can always argue different ways at their discretion and provide their own versions of interpretation. I have no intention of disputing any of them, but rather respect their opinions.

Since processing hyperspectral signatures as one-dimensional signals and processing hyperspectral images as three-dimensional image cubes are quite different, this book makes a distinction by treating hyperspectral image processing and hyperspectral signal processing in two separate categories to avoid potential confusion. To this end, three categories are specifically outlined in this book, Category A: Hyperspectral Image Processing, Category B: Hyperspectral Signal Processing and Category C: Applications.

To better serve understanding this book, a set of six chapters are included in PART I as preliminaries which cover fundamentals and basic background required for readers to have sufficient knowledge to follow algorithm design and development to be discussed in this book. Category A is made up of 15 chapters (Chapters 7-23) treated separately in four different parts, PART II-PART V. Category B consists of 6 chapters (Chapters 24-29) in two separate parts, PART VI and PART VII. Finally, applications make up Category C.

It is worth noting that many materials presented in this book have been only available after Chang (2003a). Theses include endmember extraction (Chapters 7-11), algorithm design using different levels of information (supervised linear hyperspectral mixture analysis in Chapters 12-15), pixel characterization and analysis (unsupervised hyperspectral analysis in Chapters 16-18), exploitation-based hyperspectral information compression (Chapters 19-23), hyperspectral signature coding and characterization (Chapters 24-29) and Chapters 30-32 in Category C.

There are three most interesting and unique features in this book that cannot be found in Chang (2003a), (1) PART I: Preliminaries (Chapters 2-6), (2) extensive studies of using synthetic image-based experiments for performance evaluation and (3) an appendix on algorithm compendium which compiles recently developed signal processing algorithms developed in the RSSIPL, all of which are believed to be useful and beneficial to those who design and develop algorithms for hyperspectral signal/image processing. Because this book also expands its coverage to address many issues which are not investigated and explored in Chang (2003a), it can be used in conjunction with Chang (2003a) without much overlap where the latter provides necessary basic background in design and development of statistical signal processing algorithms for hyperspectral image analysis, especially for subpixel detection and mixed pixel classification. Therefore, on the one end, those who have been involving in hyperspectral imaging and are familiar with hyperspectral imaging techniques will find this book useful and can further use it for a reference book. On the other end, those who

are new will find this book a good reference that guides them to the topics that may interest them.

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Magnetic Resonance Imaging (MRI). Chapter 32 is indeed a culmination resulting from such a great working relationship.

As a final note, this book was supposedly to be delivered by 2008. Several reasons have pushed back its original schedule. The most important factor which causes such delay is that hyperspectral data analysis has advanced so fast that many research reports have kept popping out during the course of writing this book. It is very difficult and challenging to keep track of such new developments. So, it comes to a point that this practice must be stopped at somewhere. Accordingly, I have decided to move some most recently developed research works in my laboratory to a new book, entitled, *Real Time Hyperspectral Image Processing* to be published at the end of 2012 by Springer-Verlag. Nevertheless, this book has still grown three times larger than what I originally proposed for this book. For those who are interested in my forthcoming 2012 book they can have a quick peek of these topics briefly discussed in Chapter 33, which includes a new development of Virtual Dimensionality (VD), real-time and progressive processing of endmember extraction, unsupervised target detection, anomaly detection as well as their Field Programmable Gate Array (FPGA) implementations.

Chein-I Chang (張建禕)

*Professor of Electrical Engineering
Remote Sensing Signal and Image Processing Laboratory (RSSIPL)
University of Maryland, Baltimore County
Baltimore, Maryland
USA*

*Chair Professor of Remote Sensing Technology
National Chung Hsing University
Taichung, Taiwan
Republic of China*

*Distinguished Professor
Providence University
Taichung, Taiwan
Republic of China*

*Technical Advisor
Center for QUantitative Imaging in Medicine (CQUIM)
Taichung Veterans General Hospital
Taichung, Taiwan
Republic of China*

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