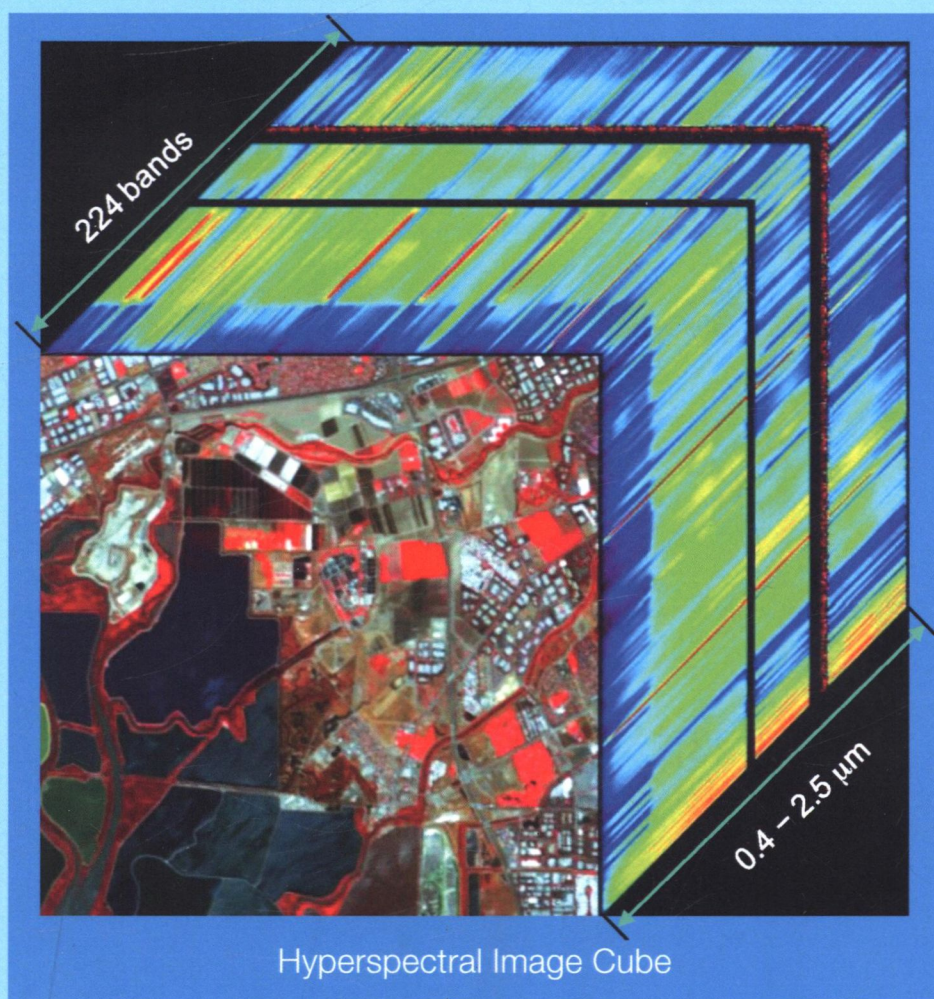


Taylor & Francis Series in Remote Sensing Applications

Qihao Weng, Series Editor

# Hyperspectral Remote Sensing

*Fundamentals and Practices*



Ruiliang Pu



CRC Press  
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# Hyperspectral Remote Sensing

"This masterful book provides a comprehensive and much-needed overview of hyperspectral remote sensing and imaging spectroscopy. Covering characteristics of field, aerial, and satellite-borne sensors, the pre-processing and analysis of hyperspectral data, available software packages, and a wide array of applications, this book will be the key reference for students and professionals. The engaging style, detailed theoretical background, and numerous practical insights offer an unparalleled treatment of the subject."

—**Timothy Warner**, Professor, West Virginia University, USA

"The quantitative retrieval of biophysical properties of the Earth's surface from remote sensing has become a reality over the past twenty years, largely because of the synergistic development of hyperspectral sensors and detailed physical models of the interaction of electromagnetic radiation for a range of Earth surface classes. Implicit in these successes is an in-depth understanding of the corrections to be applied to the sensor data and the specific analysis approaches for each surface type, suited to the available spectral detail. Ruiliang Pu's comprehensive and timely book reflects the author's intimate experience with all aspects of hyperspectral remote sensing, including applications—an invaluable work for students and professionals alike!"

—**John R. Miller**, Professor, York University, Toronto, Ontario, Canada

"... an excellent resource for both research and classroom needs. Concepts and applications are presented clearly and in a user-friendly fashion. The hyperspectral sections, especially, provide excellent content both in theory and applications. This is, and will be, a wonderful resource for the current generation of remote sensing scientists and students."

—**Arturo Sanchez-Azofeifa**, Professor, University of Alberta, Canada

Built on the author's extensive research experience, "***Hyperspectral Remote Sensing: Fundamentals and Practices***":

- Presents a complete coverage for HRS, from concepts, principles, methods, techniques to applications.
- Delivers a full survey of characteristics and types of bio-instruments, field spectrometers, air and space-borne hyperspectral sensors, systems, and missions.
- Details algorithms, techniques, and methods for radiometrically correcting, processing and analyzing hyperspectral data.
- Introduces features and modules of operational tools and software for processing hyperspectral data.
- Provides a comprehensive literature overview on different application areas of HRS: geology, soil, vegetation, ecosystem, and environment.



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# Pushing the Hyperspectral Remote Sensing



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## Fundamentals and Practices

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# Hyperspectral Remote Sensing

## Fundamentals and Practices

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*This book is dedicated to my wife, Guoling, and two sons, William and Wilson,  
for their constant support during the course of my preparing this book.*





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# Foreword

Hyperspectral remote sensing has been a frontier of geospatial technology since the late 1980s, first with the launch of airborne sensors, and later, in the 1990s, with the addition of spaceborne sensors. Today, we can witness the maturity of hyperspectral remote sensing from its wide range of applications, readily available software for image processing, and large volume of pertinent publications. With the expectation of future satellite missions of hyperspectral imaging with global coverage and increasing improvement in image-processing efficiency and information extraction effectiveness, hyperspectral remote sensing will usher in an era of reinvention with the integrated use of high spatial and temporal resolution, LiDAR, and radar sensing. In this context, I am pleased that Dr. Ruiliang Pu has the vision and energy to have written a book on this important topic.

The book provides an exhaustive review of the characteristics of airborne and spaceborne hyperspectral sensors, systems, and missions; it discusses in detail the algorithms, techniques, and methods for processing and analyzing hyperspectral data. Further, the author assesses the features and modules of operational tools and software for processing hyperspectral data, followed by a comprehensive investigation of hyperspectral remote sensing applications to geology, soils, vegetation, and environments. Dr. Pu instills his research of more than two decades and rich teaching experience across the Pacific Ocean into the writing of this book. It is a one-of-a-kind textbook, as well as research monograph. I plan to use this book for my multiple remote sensing classes.

This book is the sixteenth volume in the Taylor & Francis Series in Remote Sensing Applications, and 2017 marks the tenth anniversary of this series. As envisioned in 2007, the books in the series contribute to advancements in theories, methods, techniques, and applications of remote sensing in various fields. In fact, as seen today, many of the books in the series have served well as references for professionals, researchers, and scientists, and as textbooks for teachers and students throughout countries all over the world. I hope that the publication of this book will promote a wider and deeper appreciation and application of hyperspectral remote sensing technology. Finally, my hearty congratulations go to Dr. Pu for creating a new milestone in the history of remote sensing.

**Qihao Weng, PhD**

*Series Editor*

*Hawthorn Woods, Indiana*





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# Preface

Remote sensors can be seen widely in the biological world, and they have existed for at least hundreds of millions of years. Eyes, ears, and noses of animals are such examples. Even the skin of a living animal contains sensing cells for heat. Remote sensing devices made by humans have a much shorter history—less than 200 years—but at their first appearance, they have shown a unique capability not possessed by biological sensors: recording. From the first photographing device invented by Joseph Nicéphore Niépce in the 1820s to the first phonograph device invented by Thomas Edison in 1877, all have recording capabilities. These expanded the memorizing capability of images and sounds of biological systems. The technology has since evolved through electrical, magnetic, and into the present digital age. In the 1950s, multispectral scanners were first put on board airplanes to take multispectral images of the land. Such images contain 4 to 12 spectral bands, with some bands expanding human vision from the visible spectral range to the shorter wavelength range of ultraviolet and the longer wavelength range of near infrared, both not visible to human eyes. Although it was not until 1962 that remote sensing as a term came into being, the history of remote sensing can be traced back to the advent of photography. In the past 200 years or less, remote sensing has brought waves of excitement to human society, among which is the invention of an airborne imaging spectrometer by Alex Goetz and his colleagues in the 1980s. The principle of an airborne imaging spectrometer is similar to a multispectral scanner but can produce images in several dozen to several hundred spectral bands. Essentially, imaging spectrometers made continuous spectroscopic airborne imaging possible. To make this type of data and associated analysis distinguishable from traditional multispectral remote sensing, it was natural to choose hyperspectral remote sensing.

The strength of hyperspectral remote sensing is the detailed recording of spectroscopic properties of the imaged area. The large number of spectral bands, however, also limited the level of detail obtainable in the spatial aspects. In satellite remote sensing, a tradeoff must be done between the spectral and spatial level of details. Since hyperspectral data emphasizes the spectral aspects, either the spatial resolution or the spatial coverage cannot be great. This is why we have not yet been able to enjoy a full coverage of the world with hyperspectral data in relatively high resolution. Since technologies of data storage capacity and bandwidth of data transmission have sufficiently advanced, I think the remote sensing community will not need to wait long for the time in which we are able to make use of hyperspectral images with global coverage and sufficiently high spatial resolution.

With a background in forestry, Ruiliang Pu began hyperspectral remote sensing research when he visited Professor John Miller at the Institute of Space and Terrestrial Science located at York University in 1990. As a physicist, Professor Miller had been collaborating with foresters such as Professor Barry Rock at the University of New Hampshire and Professor Dick Waring at Oregon State University. This gave Dr. Pu a great opportunity to learn from those pioneers at a time that the application of hyperspectral remote sensing in the field of forestry had just started. He participated in a NASA project led by Dick Waring and David Peterson, the Oregon Transect Ecosystem Research. As a result, he and his colleagues published the first paper on the use of hyperspectral images in the estimation of forest leaf area index in 1992. Over the past 25 years, Dr. Pu has worked continuously on the application of hyperspectral remote sensing to various environmental problems. He has become an authority in this field.

I am pleased to be among the first few readers of this book. It first introduces the various field spectrometer devices, airborne and spaceborne hyperspectral sensors. It then introduces the radiometric processing of hyperspectral images. A large collection of various data processing algorithms and corresponding software packages is then presented. The remainder of this book introduces the application of hyperspectral remote sensing in studies of geology, vegetation, soils, water, and

atmosphere. This book is well written, with detailed coverage of methods of data analysis. It will be particularly useful to students and researchers who wish to use hyperspectral remote sensing data. I hope readers will enjoy this book as much as I do.

**Peng Gong**

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Tsinghua University  
Beijing, China*

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# Acknowledgments

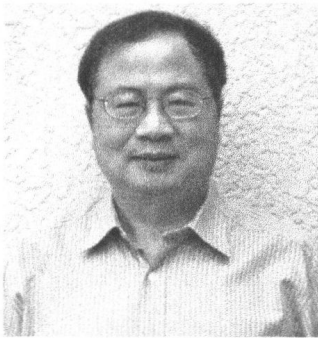
Like most books, the successful completion of this book is due to many people's contributions, support, and assistance. First of all, I must express my gratitude to Professor Peng Gong at University of California at Berkeley (UCB), USA, and Tsinghua University, China, for his invaluable supervisorship, guidance, collaboration, brotherliness, and financial support to all my research projects on HRS theoretical and application studies at UCB. I greatly appreciate Dr. Qihao Weng, Professor at Indiana State University, USA, and Series Editor for Remote Sensing Applications (Taylor & Francis Publishing Group), for his consistent encouragement and recommendation. I would also like to thank my former supervisor Professor John R. Miller at York University, Canada, for his guidance of my research on HRS in the early 1990s. I am grateful to University of South Florida for granting me a sabbatical leave in fall of 2015 to complete part of the book writing process and for the financial support to publish the book. I gratefully acknowledge all assistance from Irma Shagla Britton (senior editor) and Claudia Kisielewicz (editorial assistant), as well as all other staff at Taylor & Francis Publishing Group. Finally, I would like to express my most sincere appreciation to my lovely wife, Guoling, for her endless support and encouragement.





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# Author



**Dr. Ruiliang Pu** is currently an associate professor in the School of Geosciences at the University of South Florida (USF). He earned his MSc in forest management from Nanjing Forestry University (NFU), China, in 1985. He earned a PhD in cartography and geographic information systems in 2000, conducted at University of California (UC) at Berkeley, from the Chinese Academy of Sciences. His research experience and interests are in remote sensing, GIS and spatial statistics with direct applications to natural hazard monitoring, land use/cover change detection, biophysical and biochemical parameters extraction, and coastal and terrestrial ecosystems modeling. Dr. Pu's research projects have been funded mostly by the Natural Science Foundation

of China and NASA. He has published more than 100 journal papers, book chapters, and segments in English; and more than 25 journal papers and books in Chinese. He has been a reviewer of NASA (United States), NSERC (Canada), and Belgian Science Policy research proposals and of papers for more than 20 journals. Dr. Pu is currently an editorial board member/academic editor of *Remote Sensing* and *Geosciences* of MDPI.

