

# **Advances in Mapping from Remote Sensor Imagery**

Techniques and Applications



**Xiaojun Yang ■ Jonathan Li**



CRC Press  
Taylor & Francis Group

# Advances in Mapping from Remote Sensor Imagery

Techniques and Applications

EDITED BY

Xiaojun Yang ■ Jonathan L



**CRC Press**

Taylor & Francis Group

Boca Raton London New York

CRC Press is an imprint of the  
Taylor & Francis Group, an informa business

MATLAB® and Simulink® are trademarks of The MathWorks, Inc. and are used with permission. The MathWorks does not warrant the accuracy of the text or exercises in this book. This book's use or discussion of MATLAB® and Simulink® software or related products does not constitute endorsement or sponsorship by The MathWorks of a particular pedagogical approach or particular use of the MATLAB® and Simulink® software.

CRC Press  
Taylor & Francis Group  
6000 Broken Sound Parkway NW, Suite 300  
Boca Raton, FL 33487-2742

© 2013 by Taylor & Francis Group, LLC  
CRC Press is an imprint of Taylor & Francis Group, an Informa business

No claim to original U.S. Government works

Printed in the United States of America on acid-free paper  
Version Date: 20121031

International Standard Book Number: 978-1-4398-7458-5 (Hardback)

This book contains information obtained from authentic and highly regarded sources. Reasonable efforts have been made to publish reliable data and information, but the author and publisher cannot assume responsibility for the validity of all materials or the consequences of their use. The authors and publishers have attempted to trace the copyright holders of all material reproduced in this publication and apologize to copyright holders if permission to publish in this form has not been obtained. If any copyright material has not been acknowledged please write and let us know so we may rectify in any future reprint.

Except as permitted under U.S. Copyright Law, no part of this book may be reprinted, reproduced, transmitted, or utilized in any form by any electronic, mechanical, or other means, now known or hereafter invented, including photocopying, microfilming, and recording, or in any information storage or retrieval system, without written permission from the publishers.

For permission to photocopy or use material electronically from this work, please access [www.copyright.com](http://www.copyright.com) (<http://www.copyright.com/>) or contact the Copyright Clearance Center, Inc. (CCC), 222 Rosewood Drive, Danvers, MA 01923, 978-750-8400. CCC is a not-for-profit organization that provides licenses and registration for a variety of users. For organizations that have been granted a photocopy license by the CCC, a separate system of payment has been arranged.

**Trademark Notice:** Product or corporate names may be trademarks or registered trademarks, and are used only for identification and explanation without intent to infringe.

Visit the Taylor & Francis Web site at  
<http://www.taylorandfrancis.com>

and the CRC Press Web site at  
<http://www.crcpress.com>

# **Advances in Mapping from Remote Sensor Imagery**

**Techniques and Applications**

---

# Preface

---

Remote sensing is the science and technology of acquiring the information about physical objects and the environment through recording, measuring, and interpreting imagery and digital representations of electromagnetic radiations derived from noncontact sensors. With the recent advancement in data, technologies, and theories in the broad arena of remote sensing, the use of different aerospace remote sensors and related information extraction techniques to support various mapping applications has received more attention than ever.

This book reviews some of the latest developments in remote sensing and information extraction techniques when applying for topographic and thematic mapping. This is an area in which many exciting advancements have been made over the past decade. This book includes a total of 16 chapters, falling into three major parts. The first part (Chapters 1–3) provides an overview on modern photogrammetry, light detection and ranging (LiDAR) remote sensing, and advanced image classification methods. The second part (Chapters 4–7) reviews the utilities of remote sensing and related image-processing techniques for extracting several types of geographic features that are essential for topographic map production, including elevation, shorelines, and human settlements. The third and final part (Chapters 8–16) showcases some of the latest developments in the synergistic use of remote sensing and relevant data-processing techniques for thematic mapping in environmental and ecologic domains.

This book is the result of extensive research by interdisciplinary experts and will appeal to students, researchers, and professionals dealing with remote sensing, photogrammetry, cartography, geographic information systems, geography, and environmental science. The editors are grateful to all of those who contributed papers and revised their papers one or more times as well as those who reviewed papers according to our requests and timelines. The book project would not have been completed without the help and assistance from several staff members at CRC/Taylor & Francis Group, especially LiMing Leong, Simon Bates, Jennifer Stair, Irma Shagla-Britton, and Saprik Khairunnisa. Acknowledgment also is due to

Haowen Han and Marc Johnston of Cenveo Publisher Services for their help and assistance in this book project.

**Xiaojun Yang**  
*Tallahassee, Florida*

**Jonathan Li**  
*Waterloo, Canada*

MATLAB® is a registered trademark of The MathWorks, Inc. For product information, please contact:

The MathWorks, Inc.

3 Apple Hill Drive

Natick, MA 01760-2098 USA

Tel: 508-647-7000

Fax: 508-647-7001

E-mail: [info@mathworks.com](mailto:info@mathworks.com)

Web: [www.mathworks.com](http://www.mathworks.com)

---

## Editors

---

**Xiaojun Yang** is with the Department of Geography at Florida State University. His research focuses on the development of geospatial science and technology to support geographic inquiries in urban and environmental domains. He has authored or coauthored more than 80 English publications, including five books with John Wiley, Springer, and Taylor & Francis. He currently serves the second term as chair of the ICA Commission on Mapping from Remote Sensor Imagery (2011–2015) and director of Cartography and Geographic Information Society (2012–2016).

**Jonathan Li** is professor of geomatics at the University of Waterloo in Canada. His research interests include remote sensing, mobile mapping, and geographic information systems. He has authored more than 180 publications. He is vice chair of the International Cartographic Association (ICA) Commission on Mapping from Remote Sensor Imagery and chair of the ISPRS Intercommission Working Group V/I on Land-Based Mobile Mapping Systems.

---

# Contributors

---

**Piero Boccoardo** is an associate professor in surveying and mapping at Politecnico di Torino, Italy. He is director of information technology for humanitarian assistance, cooperation and action. He has served as president of the Italian Association for Remote Sensing since 2011 and chair of Working Group VIII/1 Disaster Management of the International Society for Photogrammetry and Remote Sensing (ISPRS). He has authored more than 110 publications.

**Guolin Cai** is a lecturer of remote sensing at the Southwest Jiaotong University in China. His research interest centers on radar interferometry for mapping regional topography and deformation.

**Glenn Campbell** currently lectures in surveying and spatial science at the University of Southern Queensland, Australia. He obtained a doctorate from the University of Queensland in remote sensing of water quality. His research focuses on developing remote-sensing applications for monitoring environmental conditions in a range of aquatic and terrestrial environments, and he is a member of the Spatial Analysis and Modelling research group of the Australian Centre for Sustainable Catchments.

**Qiang Chen** is an associate professor of photogrammetry and remote sensing at the Southwest Jiaotong University, China. His research interest centers on topographic mapping and deformation monitoring with digital photogrammetry and radar interferometry. He is the author of 2 books and 30 papers.

**Zheng Cui** is a research associate and IT administrator of the International Hurricane Research Center. He is a doctoral candidate of the School of Computing and Information Sciences at Florida International University in Miami, Florida. His research focuses on airborne LiDAR and ranging data-processing and algorithm development.



**Nate Currit** is an associate professor of geography at Texas State University-San Marcos, in San Marcos, Texas. His main research interest is in applying advanced GIS methodologies to understanding human–environment interaction across spatiotemporal scales of analysis.

**Xiaoli Ding** is chair professor of geomatics at the Hong Kong Polytechnic University. His main research interests are in satellite positioning, radar interferometry, and geohazards studies. He is the author of one book and more than 300 papers. He is a fellow of the International Association of Geodesy.

**Daniel Dzurisin** is a geologist at the U.S. Geological Survey (USGS) Cascades Volcano Observatory (CVO) in Vancouver, Washington, specializing in volcano deformation. He served as the CVO scientist-in-charge from 1994 to 1997 and currently is chief of the Interferometric Synthetic Aperture Radar (InSAR) Applied to Volcano Studies project. His research is directed toward understanding volcanic unrest using various geodetic techniques, including leveling, global navigation satellite systems, and satellite InSAR. His study areas include Mount St. Helens, the Three Sisters volcanic center, Yellowstone caldera, and volcanoes in the Aleutian arc. His book, *Volcano Deformation: Geodetic Monitoring Techniques*, was published by Springer-Praxis in 2007.

**Amy E. Frazier** is a doctoral candidate in the Department of Geography at the State University of New York at Buffalo. Her research interests focus on modeling the spatial patterns of invasive species and integrating subpixel remote-sensing classifications with landscape ecology.

**Dean B. Gesch** is a research physical scientist with the USGS at the Earth Resources Observation and Science Center in Sioux Falls, South Dakota. His research interests include topographic change detection and monitoring, sea-level rise impact assessment, elevation data accuracy assessment, and development of topographic data and derivative products. He was the lead scientist for the development of several national and global topographic data sets, including the U.S. National Elevation Dataset, and the global products GTOPO30 and GMTED2010. He served as guest editor for a special issue of *Photogrammetric Engineering & Remote Sensing* on the Shuttle Radar Topography Mission.

**Ayman F. Habib** is a professor at the Department of Geomatics Engineering at the University of Calgary, Canada. His research interests span the fields of terrestrial and aerial mobile mapping systems, modeling the perspective geometry of nontraditional imaging scanners, automatic matching and change detection, automatic calibration of low-cost digital cameras, object recognition in imagery, LiDAR mapping, and integrating photogrammetric

data with other sensor data sets. He has authored more than 250 publications. He has received several awards from the American Society for Photogrammetry and Remote Sensing (ASPRS) and ISPRS.

**Collin Homer** is the chief for the Land Characterization and Trends Team for the USGS at Earth Resources Observation and Science in Sioux Falls, South Dakota. He has focused the past 20 years on multiscale remote-sensing applications for land cover characterization and change analysis throughout the United States. His research efforts have focused on developing landscape-scale remote-sensing models, methods, and databases such as the National Land Cover Database. He is the coordinator of the federal agency Multi-Resolution Land Characteristics Consortium that coordinates national land cover production for 10 agencies.

**Patricia A. Houle** is an instructor in the Department of Earth and Environment at Florida International University in Miami, Florida. She currently teaches courses in environmental science and social science and is engaged in postgraduate studies in curriculum and instruction with a concentration in science education.

**Hyung-Sup Jung** is an assistant professor in the Department of Geoinformatics at the University of Seoul. He is a principal investigator or coinvestigator of several projects on the development of SAR, InSAR, and InSAR altimeter techniques for the measurement of surface deformation and moving object's velocity, precise 3D geopositioning, and forest height estimation.

**Tae-Jung Kwon** is a doctoral student in the Department of Civil and Environmental Engineering at the University of Waterloo in Canada. His research interests include remote sensing, geographic information systems, and system modeling and optimization.

**Chang-Wook Lee** is a research professor in the Department of Geoinformatics at the University of Seoul. His research interests include the development of small baseline subsets (SBAS) and persistent scatterer (PS) InSAR techniques and their applications to the study of earthquake, volcanic activities, and land subsidence.

**Wonjin Lee** is a doctoral candidate in the Department of Geoinformatics at the University of Seoul. His research interests include developing InSAR and GPS technologies for mapping ground deformation.

**Jonathan Li** is professor of geomatics at the University of Waterloo in Canada. His research interests include remote sensing, mobile mapping, and geographic information systems. He has authored more than 180

publications. He is vice chair of the International Cartographic Association (ICA) Commission on Mapping from Remote Sensor Imagery and chair of the ISPRS Intercommission Working Group V/I on Land-Based Mobile Mapping Systems.

**Chunhua Liao** is pursuing her Master of engineering degree in photogrammetry and remote sensing at Peking University in Beijing. Her research interests include hyperspectral data processing and analysis and vegetation dynamics mapping. She is also the author of more than 10 papers.

**Guoxiang Liu** is professor of remote sensing at the Southwest Jiaotong University in China. His research interests are radar interferometry, photogrammetry, and radargrammetry for mapping regional topography and deformation. He is the author of two books and more than 100 papers. He is a member of the ICA Commission on Mapping from Remote Sensor Imagery and a member of the ISPRS Inter-Commission Working Group V/I.

**Zhong Lu** is a physical scientist with the USGS in Vancouver, Washington. He is a principal investigator of several projects funded by the USGS, NASA, and European, Japan and German Space Agencies on the study of land surface deformation using satellite InSAR. His research interests include technique developments of SAR, InSAR, and persistent-scatterer InSAR processing, and applications of InSAR on natural hazards monitoring and natural resources management. He has authored or coauthored more than 100 publications.

**Xiaojun Luo** is a lecturer of remote sensing at the Southwest Jiaotong University, China. His research interest centers on topographic mapping and deformation monitoring with radar interferometry.

**Xuelian Meng** is an assistant professor in the Department of Geography and Anthropology at Louisiana State University. Her research interests include land use and land cover mapping, LiDAR-based urban structure analysis, image processing and feature extraction, and 3D topographic modeling.

**Soe W. Myint** is associate professor of geographical sciences at Arizona State University. He is a senior sustainability scientist at the Global Institute of Sustainability and is affiliated with the GeoDa Center for Geospatial Analysis and Computation, Decision Center for a Desert City, and Central Arizona Phoenix-Long Term Ecological Research at ASU. His research interest centers on geographic information systems, geospatial statistics, spatial modeling, and remote sensing. He is currently serving as a lead scholar of the International Research Training Group of the University of

Kaiserslautern, Germany, and chair of the Remote Sensing Specialty Group of the Association of American Geographers (AAG).

**Mahesh Pal** received his doctoral degree from the University of Nottingham. He is an associate professor with the Department of Civil Engineering, National Institute of Technology, Kurukshetra, India. His major research areas include land-cover classification, feature selection, and application of artificial intelligence techniques in various civil engineering applications. He has published more than 80 research papers and is in the editorial board of Remote Sensing Letters. He is a fellow of Institution of Engineers (India).

**Christopher E. Parrish** is the lead physical scientist in the Remote Sensing Division of NOAA's National Geodetic Survey (NGS) and NGS project manager for Integrated Ocean and Coastal Mapping (IOCM). He holds an appointment as affiliate professor of Earth sciences and ocean engineering at the University of New Hampshire (UNH) and is based at the NOAA-UNH Joint Hydrographic Center-Center for Coastal and Ocean Mapping (JHC-CCOM). His primary research interests include full-waveform light detection and ranging, sensor modeling and calibration, uncertainty analysis, and coastal mapping applications. He is serving as assistant director of the ASPRS LiDAR Division and past president of ASPRS Potomac Region.

**Ruiliang Pu** is an associate professor of geography, environment, and planning at the University of South Florida, Tampa Bay. His research interest centers on applications of remote sensing, geographic information systems, and spatial statistics to natural hazard monitoring, land use and cover change detection, biophysical and biochemical parameters extraction, and coastal and terrestrial ecosystems modeling. He is the author and coauthor of two books and more than 80 papers.

**Fabio Giulio Tonolo** is a senior researcher at Information Technology for Humanitarian Assistance, Cooperation and Action, Italy. His research interest is mainly on the use of satellite imagery and geospatial data to support emergency response activities. He is secretary of the ISPRS Working Group VIII/1 Disaster Management.

**Le Wang** is an associate professor of geography at the State University of New York, Buffalo. His research interests include the development of advanced remote-sensing techniques for estimating small-area urban populations, mapping and monitoring coastal mangrove forests, and mapping and modeling the spread of invasive species. He has authored more than 40 refereed journal articles and four book chapters. He was the recipient of the 2008 Early Career Award from the Remote Sensing Specialty Group of the AAG.

**George Xian** is a research scientist at the USGS Earth Resources Observation and Science Center. His research interests include land remote-sensing data application for terrestrial ecosystems change analysis, climate change, and environmental modeling.

**Xiaojun Yang** is with the Department of Geography at Florida State University. His research focuses on the development of geospatial science and technology to support geographic inquiries in urban and environmental domains. He has authored or coauthored more than 80 English publications, including five books with John Wiley, Springer, and Taylor & Francis. He currently serves the second term as chair of the ICA Commission on Mapping from Remote Sensor Imagery (2011–2015) and director of Cartography and Geographic Information Society (2012–2016).

**Keqi Zhang** is the interim director of the International Hurricane Research Center and an associate professor in the Department of Earth and Environment at Florida International University in Miami, Florida. His research focuses on airborne light detection and ranging mapping, beach erosion, storm surge modeling, coastal responses to climate changes and human activity, and 3D visualization animation. He has authored more than 70 publications.

**Lei Zhang** is a research associate at the Hong Kong Polytechnic University. His research interests include developments of advanced multitemporal InSAR processing techniques and their applications on natural hazard monitoring and natural resources management.

**Xianfeng Zhang** is an associate professor at the Institute of Remote Sensing and Geographic Information Systems, Peking University, China. His research interest is focused on remote sensing of ecology, hyperspectral data processing, and data assimilation, and he is the author of 4 books and more than 60 papers. He is a member of the Scientific Committee of the ISRS GI4DM and a corresponding member of the ICA Commission on Mapping from Remote Sensor Imagery.

---

# Contents

---

<i>Preface</i>	vii
<i>Editors</i>	ix
<i>Contributors</i>	xi
<b>1 Modern photogrammetric mapping</b>	<b>1</b>
AYMAN F. HABIB	
<b>2 Airborne LiDAR remote sensing and its applications</b>	<b>33</b>
KEQI ZHANG, ZHENG CUI, AND PATRICIA A. HOULE	
<b>3 Advanced algorithms for land use and cover classification</b>	<b>69</b>
MAHESH PAL	
<b>4 Global digital elevation model development from satellite remote-sensing data</b>	<b>91</b>
DEAN B. GESCH	
<b>5 Digital elevation model generation from satellite interferometric synthetic aperture radar</b>	<b>119</b>
ZHONG LU, HYUNG-SUP JUNG, LEI ZHANG, WONJIN LEE, CHANG-WOOK LEE, AND DANIEL DZURISIN	
<b>6 Shoreline mapping</b>	<b>145</b>
CHRISTOPHER E. PARRISH	
<b>7 Seeing residential buildings from remotely sensed imagery: An object-oriented approach</b>	<b>169</b>
XUELIAN MENG, NATE CURRIT, LE WANG, AND XIAOJUN YANG	

<b>8 Assessment of urbanization patterns and trends in the Gulf of Mexico region of the southeast United States with Landsat and nighttime lights imagery</b>	<b>185</b>
GEORGE XIAN AND COLLIN HOMER	
<b>9 Fractional vegetation cover mapping from the HJ-1 small satellite hyperspectral data</b>	<b>203</b>
XIANFENG ZHANG AND CHUNHUA LIAO	
<b>10 Estimating and mapping forest leaf area index using satellite imagery</b>	<b>225</b>
RUILIANG PU	
<b>11 Effects of the spatial pattern of vegetation cover on urban warming in a desert city</b>	<b>261</b>
SOE W. MYINT	
<b>12 Remote sensing of algal blooms in inland waters using the matrix inversion method and semiempirical algorithms</b>	<b>279</b>
GLENN CAMPBELL	
<b>13 Advanced geospatial techniques for mapping and monitoring invasive species</b>	<b>307</b>
LE WANG AND AMY E. FRAZIER	
<b>14 Surface deformation mapping with persistent scatterer radar interferometry</b>	<b>329</b>
GUOXIANG LIU, LEI ZHANG, XIAOLI DING, QIANG CHEN, XIAOJUN LUO, AND GUOLIN CAI	
<b>15 Mapping marine oil spills from space</b>	<b>361</b>
TAE-JUNG KWON AND JONATHAN LI	
<b>16 Remote-sensing techniques for natural disaster impact assessment</b>	<b>387</b>
PIERO BOCCARDO AND FABIO GIULIO TONOLO	
<i>Index</i>	<b>415</b>

# Modern photogrammetric mapping

Ayman F. Habib

---

## CONTENTS

- 1.1 Introduction ..... 2
- 1.2 Photogrammetric principles..... 2
- 1.3 Calibration and stability analysis of medium-format digital cameras..... 5
- 1.4 GNSS/INS-assisted photogrammetric mapping systems..... 9
- 1.5 System calibration..... 11
- 1.6 Photogrammetric mapping with line cameras..... 16
- 1.7 Feature-based photogrammetry..... 18
  - 1.7.1 Linear features..... 19
  - 1.7.2 Areal features ..... 21
- 1.8 Integration of photogrammetric and LiDAR data ..... 22
- 1.9 Conclusion..... 26
- References ..... 27

Photogrammetric mapping is traditionally defined as the art and science of generating three-dimensional (3D) spatial and descriptive information from imagery. Photogrammetric mapping is a well-established discipline. In the past few years, however, several technical advances have had an impact on the photogrammetric mapping process—for example, integrated Global Navigation Satellite System and Inertial Navigation System (GNSS/INS) units, medium-format digital cameras, light detection and ranging (LiDAR) systems, and advanced image-processing techniques. This chapter will provide insight into the impacts of recent technical advances in the data acquisition and processing systems on photogrammetric mapping operations. The chapter begins with a brief introduction of the photogrammetric mapping principles. Then, it proceeds with a discussion of the impact of these advances on the photogrammetric mapping practices.



## 1.1 INTRODUCTION

Photogrammetric mapping is traditionally defined as the art and science of generating three-dimensional (3D) spatial and descriptive information from imagery. Photogrammetric mapping is a well-established discipline. In the past few years, however, several technical advances have had an impact on the photogrammetric mapping process—for example, integrated Global Navigation Satellite System and Inertial Navigation System (GNSS/INS) units, medium-format digital cameras, light detection and ranging (LiDAR) systems, and advanced image-processing techniques. This chapter will provide some insight into the impacts of recent technical advances in the data acquisition and processing systems on photogrammetric mapping operations. The chapter begins with a brief introduction of the photogrammetric mapping principles. Then, it proceeds with some discussion related to the following issues:

1. Calibration and stability analysis of medium-format digital cameras for photogrammetric mapping
2. The incorporation of GNSS/INS-based position and orientation information in object space reconstruction
3. System calibration of GNSS/INS-assisted photogrammetric mapping units
4. Line cameras for photogrammetric mapping
5. Feature-based photogrammetric triangulation
6. Integration of photogrammetric and LiDAR data for orthorectification and 3D visualization

## 1.2 PHOTGRAMMETRIC PRINCIPLES

The main objective of photogrammetric mapping is the derivation of 3D coordinates of features of interest by observing their image coordinates in overlapping imagery. The mathematical model for the photogrammetric point positioning is based on the collinearity of the camera's perspective/projection center, the object point, and the corresponding image point. This model is embodied in the collinearity equations (Equation 1.1). The collinearity equations provide the mathematical expression relating the image coordinates of an image point  $(x_i, y_i)$ , the ground coordinates of the corresponding object point  $(X_i, Y_i, Z_i)$ , the ground coordinates of the perspective center  $(X_o, Y_o, Z_o)$ , the attitude of the image coordinate system relative to the ground coordinate system as defined by the elements of the rotation matrix  $(r_{11}, r_{12}, r_{13}, \dots, r_{33})$ , and the internal characteristics of the camera (principal point coordinates –  $x_p, y_p$ , principal distance –  $c$ , and deviations from the assumed collinearity condition representation by  $dist_x$  and  $dist_y$ ) (Brown, 1966):