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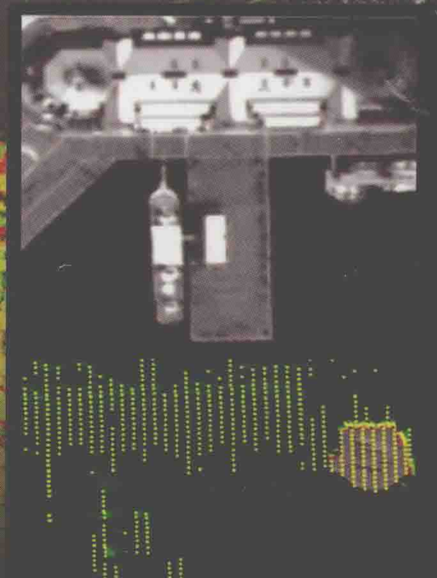

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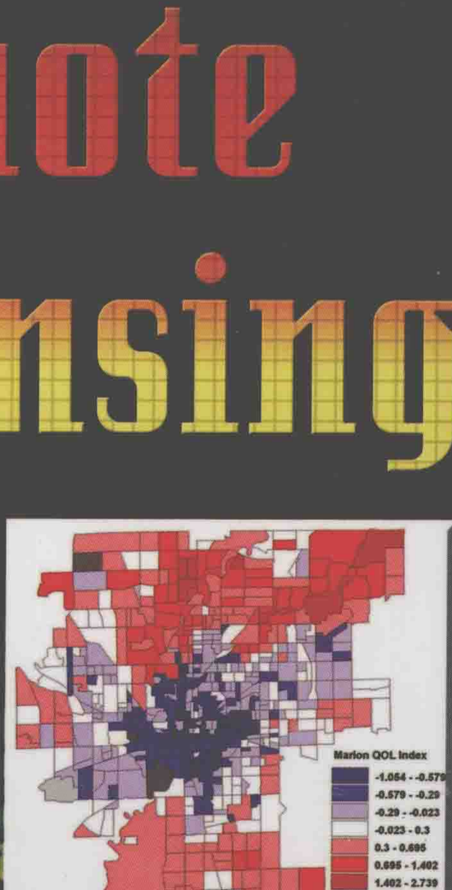

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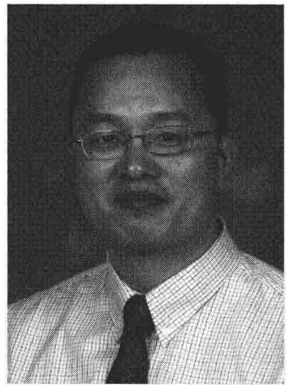
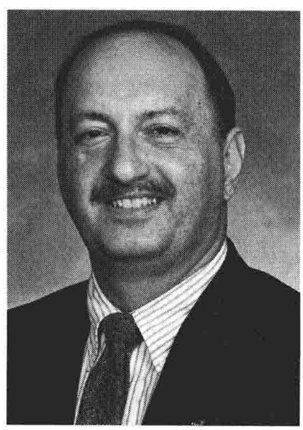
Urban Remote Sensing

Editors



Qihao Weng was born in Fuzhou, China in 1964. He received a B.A. in geography from Minjiang University in 1984, an M.S. in physical geography from South China Normal University in 1990, an M.A. in geography from the University of Arizona in 1996, and a Ph.D. in geography from the University of Georgia in 1999. He is currently an associate professor of geography and director of the Center for Urban and Environmental Change at Indiana State University. His research focuses on remote sensing and GIS analysis of urban ecological and environmental systems, land-use and land-cover change, urbanization impacts, and human–environment interactions.

Dr. Weng is the author of more than 50 peer-reviewed journal articles and book chapters. He has been the recipient of the Robert E. Altenhofen Memorial Scholarship Award by the American Society for Photogrammetry and Remote Sensing (1999) and the Best Student-Authored Paper Award from the International Geographic Information Foundation (1998). In 2006, he received the Theodore Dreiser Distinguished Research Award by Indiana State University, the university's highest research honor bestowed to faculty. He has worked extensively with optical and thermal remote sensing data, primarily for urban heat island study, land-cover and impervious surface mapping, urban growth detection, spectral mixture analysis, and socioeconomic characteristics derivation.



Dale Quattrochi is a senior research scientist with the NASA Marshall Space Flight Center in Huntsville, Alabama, and has over 26 years of experience in the field of Earth science remote sensing research and applications. Dr. Quattrochi's research interests focus on application of thermal remote sensing data for analysis of heating and cooling patterns across the diverse urban landscape as they impact overall local and regional environments. He is also conducting research on applications of geospatial statistical techniques, such as fractal analysis and multiscale remote sensing data.

Dr. Quattrochi is the recipient of numerous awards, including the NASA Exceptional Scientific Achievement Medal, NASA's highest science award, which he received for his research on urban heat islands and remote sensing. He is also a recipient of the Ohio University College of Arts and Sciences Distinguished Alumni Award. Dr. Quattrochi is the coeditor of two books: *Scale in Remote Sensing and GIS* (with Michael Goodchild), published in 1997 by CRC/Lewis Publishers, and *Thermal Remote Sensing in Land Surface Processes* (with Jeffrey Luvall), published in 2004 by CRC Press. He received his Ph.D. degree from the University of Utah, his M.S. degree from the University of Tennessee, and his B.S. degree from Ohio University, all in geography.

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An Introduction to Urban Remote Sensing

Qihao Weng and Dale A. Quattrochi

The twenty-first century is the first "urban century," according to the United Nations Development Program. The focus on cities reflects awareness of the growing percentage of the world's population that lives in urban areas. In environmental terms, as has been pointed out at the U.N. Conference on Human Settlement, cities and towns are the original producers of many of the global problems related to waste disposal and air and water pollution. The need for technologies that will enable monitoring the world's natural resources and urban assets and managing exposure to natural and man-made risks is growing rapidly.

This need is driven by continued urbanization. In 2000, about 3 billion people, representing about 40% of the world's population, lived in urban areas. Urban population will continue to rise substantially over the next several decades according to the United Nations, and most of this growth will be in developing countries. The number of megacities (i.e., cities with populations of more than 10 million) will increase to 100 by 2025. Thus, there is critical need to understand urban areas to help improve and foster environmental and human sustainability of cities around the world.

Over the past decades, the majority of remote sensing work has been focused on natural environments. Applying remote sensing technology to urban areas is relatively new. With the advent of high-resolution imagery and more capable techniques, urban remote sensing is rapidly gaining interest within the remote sensing community. Driven by advances in technology and societal needs, biannual international symposia on remote sensing of urban areas (since 1997) and remote sensing and data fusion (since 2001) have been very successful. Recently, several journals have published special issues on remote sensing of urban areas, including: *Remote Sensing of Environment*, 2003, vol. 86, issue 3; *IEEE Transactions on Geoscience and Remote Sensing*, 2003, vol. 41, issue 9; *Photogrammetric Engineering and Remote Sensing*, 2003, vol. 69, issue 9; and the *Remote Sensing of Environment* special issue on urban thermal remote sensing published in 2006. It appears that increasing numbers of universities in the United States and other countries have started offering courses on remote sensing of urban and suburban areas.

To meet the growing interest in applications of remote sensing technology to urban and suburban areas, we have assembled a team of experts to write a book on urban remote sensing. For the first time, this book systematically examines all aspects of the field. Each chapter follows a similar prototype, including such elements as literature review of basic concepts and methodologies, case studies, methods for applying up-to-date techniques, and analysis of results. This book may be used as a textbook for upper-division undergraduate and graduate students; however, it can also serve as a reference book for researchers or individuals in academia and governmental and commercial sectors who are interested in remote sensing of cities.

This book consists of five parts. Part I focuses on data, sensors, and system considerations and algorithms for urban feature extraction. Part II analyzes urban landscapes in terms of composition and structure, using subpixel analysis techniques particularly. Part III presents methods for monitoring, analyzing, and modeling urban growth. Part IV illustrates various approaches to urban planning and socioeconomic applications of urban remote sensing. Part V assesses progress made to date, identifies existing problems and challenges, and demonstrates new developments and trends in urban remote sensing.

The three chapters in Part I are concerned with extracting urban buildings and other features. These researchers utilize an electro-optical sensor and two range sensors — LIDAR and interferometric SAR, respectively. Chapter 1 describes algorithms and methods for large-scale urban orthoimage generation. The experiment conducted by these contributors in Denver, Colorado, demonstrates that buildings and bridges can be placed with accurate upright, planimetric locations and that sidewalks and roads can be completely visible. LIDAR (light detection and ranging) technology provides a unique and promising solution to extracting urban features (Ackermann, 1999). Chapter 2 presents an approach to building extraction from nonground LIDAR points, with three sequential steps: building segmentation, boundary tracing, and regulation. The approach was tested with success in urban areas in Baltimore, Maryland, Osaka, Japan, and Toronto, Canada. Chapter 3 focuses on acquisition and segmentation of interferometric SAR data for reconstruction of buildings with a model-based approach.

One of the most widely used applications of remote sensing technology in urban areas focuses on the characterization, identification, classification, and quantification of urban construction materials, composition, and structure. Chapter 4 applies the vegetation–impervious surface–soil concept (Ridd, 1995) and spectral mixture analysis technique for a subpixel analysis of the urban landscape structure and dynamics in Indianapolis, Indiana. The potentials and limitations of spectral mixture analysis for characterizing urban landscapes are also examined. Chapter 5 introduces a new approach, the Bayesian spectral mixture analysis, in which endmember spectral signatures are no longer assumed as constants. Instead, they are represented by probability density functions and thus can incorporate the natural variability of endmember spectral signatures. Because of the complexity of urban landscapes, lack of spatial consideration in traditional per-pixel classifiers, and inconsistencies between scale of observation (i.e., pixel resolution) and spatial characteristics of the target (Mather, 1999), traditional image classification approaches such as the maximum-likelihood classifier are ineffective in classifying urban land use and land cover. Chapter 6 examines how various geospatial approaches can be used to extract textures of land-use or land-cover classes to improve classification accuracy. Urban areas are characterized by a large diversity of materials, such as impervious surfaces, vegetation, soils, water, and so on. Chapter 7 applies imaging spectrometry to urban areas, especially for characterization of artificial and man-made surfaces. The authors provide a summary of the current state of knowledge of imaging spectrometry and, through case studies, also show how this technology can support urban applications.

Part III focuses on urban land-change detection, growth monitoring, modeling, and prediction. Chapter 8 applies a neural network-based spatiotemporal data mining method to simulate and predict urban expansion in St. Louis, Missouri. Chapter 9 uses subpixel impervious surfaces derived from satellite remote sensing data in conjunction with digital orthophotography to analyze urban expansion in the Las Vegas, Nevada, metropolitan area from 1984 to 2002 and in the Tampa Bay, Florida, area from 1991 to 2002. Subpixel impervious surfaces were found to be capable of providing quantitative measurements of the spatial extents, development densities, and temporal changes of urban land. Chapter 10 examines the potential of remote sensing as it may contribute to urban growth theory and modeling. By citing examples of urban dynamics analysis, this chapter has outlined a general framework for urban growth and developed the basis for combining remotely sensed data and spatial measurements (metrics) to aid in development and validation of new urban growth theory assessments.

Remote sensing data and research results have been applied to many environmental and socioeconomic applications, such as urban heat islands (Quattrochi et al., 2000; Weng, 2001), urban environmental quality (Nichol and Wong, 2005), and estimation of demographic and socioeconomic variables (Lo and Faber, 1997; Thomson and Hardin, 2000; Li and Weng, 2005). The five chapters in Part IV illustrate the current state of these applications. Chapter 11 investigates the impact of urbanization on land-surface temperatures and urban heat island phenomenon in San Juan, Puerto Rico, using remote sensing, *in situ* field measurement, and numerical modeling techniques. Chapter 12 investigates integration of environmental data sets derived from remotely sensed images with other environmental variables for assessment of urban environmental quality in Hong Kong. Urban environmental quality index maps were generated at the levels of pixels and administrative regions, with principal component analysis and GIS overlay as the methods of data integration. Chapter 13 examines various methods for population estimation and interpolation and illustrates them with specific examples. The examples in this chapter particularly highlight the use of recently available high spatial-resolution satellite data to study intraurban population characteristics. Chapter 14 provides a summary of ways in which nighttime imagery has been used to study socioeconomic variables and urban environments and suggests potential improvements on these methods if finer resolution sensors become available. In particular, the Defense Meteorological Satellite Program's Operational Linescan System (DMSP OLS) data products are explored for use in understanding urban and exurban areas. Chapter 15 develops a methodology for assessing urban quality of life based on integration of Landsat Enhanced Thematic Mapper Plus (ETM+) imagery and Census 2000 data within a GIS framework. The model developed for Marion County, Indiana, was applied to Monroe and Vigo Counties in the same state for validation.

The last part of the book is concerned with the current state of urban remote sensing, problems encountered in the past, and trends for future development.

Remote sensing of urban areas has relied primarily on three spectral regions: visible through near infrared, thermal infrared, and microwave. Chapter 16 explores strengths and weaknesses of using the middle infrared (3 to 5 μm) spectral region for characterization of urban and suburban environments and makes suggestions for future direction of development. Chapter 17 discusses recent development of very high- and ultrahigh-resolution satellite, digital airborne, and LIDAR sensors and their impacts on processing techniques. The final chapter, Chapter 18, compares the capacities and trade-offs of very high spatial resolution and very high spectral resolution sensors for urban mapping. A case study of land-cover classification around the area of the castle of Pavia, Italy suggests that when high-spectral and high-spatial resolutions are not available at the same time, the former seems to be more valuable than the latter, provided that some minimum requirements are met for both.

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