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Geo-Spatial Technologies in Urban Environments

Policy, Practice, and Pixels

Second Edition

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With 39 Figures

Springer

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Foreword

I was introduced to cities as “ecosystems” by the late Professor Forest Stearns (University of Wisconsin, Milwaukee) who was an early pioneer in the studies of the urban ecology in the 1970s. I still recall the various terms: “Urban ecosystem”, “Urban zones” Urban corridors” Megacities” or “Megacities’ complexes” and “Megalopolis” used by various discipline experts as they grappled with the complex of all the terrestrial habitats-the city. Cities have been humanity’s habitat since ancient times and one can find references to the cities even in biblical writings and other ancient texts from many parts of the world. So what is different now? It is the rate of global urbanization that has brought urban systems and urban environments into focus once again. This has captured our attention in the past several months. For example, the British Broadcasting Corporation News (BBC news) devoted a series of highly educational programs titled “Urban planet” in July 2006. I was impressed with the breadth and the depth of urban issues discussed in the series and the fact that many academic and government experts were featured to provide an assessment of the current state of global urbanization. The United Nations reports that increased urbanization has created a range of serious issues, including access to clean water, sanitation, shelter, urban poverty, HIV/AIDS and problems with urban governance, not to mention the issues related to urban environments.
What is significant is the report that sometime in 2007 and somewhere on the planet, someone migrating from a rural area to a city will tip the global urban/rural balance. United Nations agencies forecasts that majority of human population will live in urban settings very soon. These estimates indicate that about 180,000 people are being added to the urban population every day. Can the world's urban infrastructure absorb the equivalent of the population of two Toykos each year? As a news reporter put it “Homo sapiens” are fast becoming “Homo urbanis”!

In historical literature, there are fascinating examples of the use of “early forms of geospatial technologies” such as photographs of cities acquired from the hot air balloons, from cameras suspended from kites, and the very first aerial photograph of a city from Wilbur Wright’s plane in 1909 and many early maps from geographic field surveys.

As we rapidly urbanize as a society, we need to usher in new and innovative technologies, social and policy initiatives, and political and economic instruments to improve the quality of life in urban environments. A set of rapidly maturing technologies termed the “Geospatial” technologies are becoming a vital part of this new urbanized world. Geospatial technologies have already had a major impact of many aspects of how we analyze, model and manage the urban systems and their environments. From population census using remote sensing and satellite technologies to modeling the impact of a contagious disease using GIS; we have come to realize the promise and potential of these rapidly maturing technologies. Despite many strides in the application of geospatial technologies for urban applications; this science is still in its infancy.

This book edited by Ryan Jensen, Jay Gatrell, and Daniel McLean is, therefore a much awaited contribution to the literature. The editors have assembled an extraordinarily talented contributors for the book. It is a pioneering effort in many ways for it uniquely brings together the physical and social aspects of urban environments via geospatial technology applications.

The book chapters address some difficult and important aspects of application of geospatial technologies in urban environments. The authors have discussed cutting-edge geospatial technologies for issues ranging from urban change detection, estimating urban population to urban health and heat wave and urban child obesity. Chapter on role of geospatial technologies in environmental justice is a good example how social and physical aspects of urban landscape can be brought together using these technologies.
Also, the issues unique to the semi-rural counties have been addressed in the book.

I believe this timely publication will spur further development of geospatial technology applications for urban systems. Many challenges remain and need to be addressed if we are to fully apply these technologies for urban environments. I am confident that this book will inspire a new generation of researchers who will apply geospatial technologies to urban systems before the impact of rapid global urbanization becomes a crisis for our societies in both the developed and the developing world.

Kamlesh P. Lulla, Ph.D; Ph.D.
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Dedications

To my family for their inspiration and support – RRJ

To my favorite editor, s., and our children, f. m. and e. – JDG

To my wife and soul mate for your support, compassion, and challenge to be better – DDM

Acknowledgments

The editors wish to thank the excellent chapter authors for their contributions to the second volume of this book. We also acknowledge the hard work and assistance of Ms. Barbara McNeill with the final preparation of the manuscript. Finally, we would like to thank the entire Springer team for their continued help and support of our efforts.

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1 Applying Geospatial Technologies in Urban Environments

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The world has entered the urban millennium. Nearly half the world's people are now city dwellers (Annan, 2001). The city is everywhere and everything (Amin and Thrift 2002). ... Towns and cities are (the) focus of today's social and ecological problems. Urban activities are the foundation of economic prosperity. Cities are strategic places (Annan, 2001). Cities compete. Cities are going through a renaissance (Amin and Thrift, 2002).

European Science Foundation, Urban Science, 2006

1.1 About this book

As the epigraph above indicates, cities have become an important part of human existence, and they represent and support most human activity. Urban areas have been the primary locations for social movements, intellectual discoveries, and the rise and fall of nations and civilizations (Greene and Pick, 2006). It is projected that cities will only become more important as societies continue to go through the demographic transformation process. Geospatial technologies will probably play a critical role throughout this because of their ability to examine things synoptically, help manage existing infrastructure and services, and predict and model future growth.

According to the United Nations Information Service (2004), 48 per cent of the world's population lived in urban areas in 2003, and urban population is projected to exceed the 50 per cent mark by 2007. Additionally, the proportion of the world's population that is urban is expected to rise to 61 per cent by 2030. Conversely, rural population is anticipated to decline slightly from 3.3 billion in 2003 to 3.2 billion in 2030. Further, during 2000-2030, the world's urban population is projected to grow at an average annual rate of 1.8 per cent, nearly double the rate expected for the total population of the world (almost 1 per cent per year). At this rate of growth, the world's urban population will double in 38 years.

Most of the urban growth will probably occur in lesser-developed regions where the percentage of urban population is lower (42% in 2003; expected to rise to 57% by 2030). This urban growth trend in less developed regions is forecast to average 2.3 per cent per year during 2000-2030. In fact, almost all the growth of the world's total population between 2000 and 2030 is expected to be absorbed by the urban areas of less developed regions, and by 2017, the number of urban dwellers will equal the number of rural dwellers in the less developed regions (United Nations Information Service, 2004).

In contrast, the urban population of more developed regions is expected to increase very slowly, from 0.9 billion in 2003 to 1 billion in 2030, because the process of urbanization is already advanced in these regions, where 74 per cent of the population lived in 2003. The percentage of the population in more developed regions living in urban areas is expected to increase to 82 per cent by 2030 (United Nations Information Service, 2004).

As these figures and projections suggest, people will continue to migrate to urban areas – particularly in developing countries. The ability to examine and mitigate the potential negative impacts of this migration is very important today and will be even more important tomorrow. Also, the ability to adequately prepare for this migration probably will rest on the shoulders of those urban scientists currently studying the urban environment. This book presents many ways that the urban environment can be studied using geo-spatial data and techniques.

1.2 Chapters

There are many ways to classify the chapters of this book including geospatial techniques used, size of urban area studied (population, area, etc.), data sets used, spatial resolution or scale of the data and so on. Because of this breadth, classifying the chapters into specific groups was very difficult. Simply put, this book provides many examples of cutting-edge geospatial technology research in urban areas. Many chapters demonstrate the potential role of geospatial technologies in examining, mapping, and modeling urban problems. Specifically, chapter 2 describes how geospatial technologies can be used to study urban change using LIDAR and digital frame camera data. Chapter 3 shows how these technologies help to assess risk in urban areas using two case studies. Chapters 4 and 8 provide reviews the role that geospatial technologies have in measuring and modeling urban population and growth, respectively. These chapters also provide case studies to describe the concepts that are discussed. Those who wish to see how satellite remote sensing data can be used to quantify the urban forest using Artificial Neural Networks should read chapter 5. Chapter 6 describes the role of Public Participation GIS to study urban health. Chapter 7 describes how the urban environment affects childhood physical activity (and corresponding obesity). The spatial relationship of deer-vechicle collisions along the suburban fringe is presented in chapter 9, and the role that scale plays in spatial autocorrelation studies is described in chapter 10. Finally, a spatial perspective of environmental justice is presented in Chapter 11.

Table 1. . Summary of substantive chapters in this book.

	Author(s)	**Subject**
2	J. Jensen et al.	Urban change detection with digital frame and LIDAR data
3	Lawrence et al.	Geo-spatial technologies to study risk
4	Hardin et al.	Estimating urban population
5	Jensen and Hardin	Measuring urban forest canopy with remote sensing data
6	Johnson	Public Participation GIS's role in studying urban health and heat waves
7	Liu et al.	Urban physical activity and childhood obesity
8	Hardin et al.	Mapping, measuring, and modeling urban growth
9	Gonser and Horn	Deer vehicle collisions along the suburban fringe

10	Spiker and Warner	Scale considerations and spatial autocorrelation
11	Fuller et al.	Spatial imperatives of environmental justice

The authors and editors hope that the applications described in this book will serve as an impetus to better understand the complex urban environment. Indeed, the future will probably present many challenges in urban areas. These challenges may be centered on such diverse issues as environmental justice, urban quality of life, effective planning, and many others. As will be shown in this book, geospatial technologies are uniquely suited to study these and many other urban problems.

This book will help anyone concerned about the urban environment to learn about additional geospatial data and techniques to study the changing dynamics in urban areas. With so much policy discourse and concern given to many other organisms and the environments in which they live, we hope that more discourse and concern will be aimed at humans and the human environment. Further, we hope that the ideas, applications, methods, and data presented in this book will enable planners, landscape architects, urban foresters, GIS and remote sensing specialists, and many others to improve quality of life in the urban environment. Finally, we hope that the studies and methods contained within this book will be used as a point of reference for those who might imagine and re-imagine the range of potential geo-technical applications to assist urban decision making and promote the overall sustainability of social and physical systems.

As the opening epigraph of this chapter suggests, cities will continue to become very important throughout the world. Our ability to model, map, and predict changes in the urban environment will be very important as humanity becomes evermore urbanized.

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2 Remote Sensing Change Detection in Urban Environments

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2.1 Introduction

Timely and accurate change information in the urban environment is essential for successful planning and management. The change detection may range from 1) monitoring general land cover/land use found in multiple dates of imagery, to 2) anomaly (e.g., subsidence) detection on hazardous waste sites. Remote sensing approaches to change detection have been widely used due to its cost-effectiveness, extensibility, and temporal frequency. Since the advent of high-spatial resolution satellite imagery, it has become increasing popular to detect, analyze, and monitor detailed changes such as new buildings, roads, and even patios in the urban environment. Basically, there are two types of change detection methods: 1) detection of the change using various image enhancement methods, and 2) extraction of detailed types of land-cover change based on the use of classification techniques (Chan et al. 2001; Jensen 2005)

Traditional remote sensing change detection techniques, which are generally applicable to coarse spatial resolution optical imagery, include image algebra multi-band differencing (Coppin and Bauer 1996), image transformation such as principal components analysis (Collins and Woodcock 1996), and the widely used post-classification comparison method (Jensen et al. 1995). More recent change detection methods are based on expert systems, artificial neural networks, fuzzy sets, and object-oriented approaches. These change detection methods are explained in Lu et al. (2004) and Jensen (2005).

This chapter provides several examples of remote sensing change detection based on new change detection techniques using the remote sensor data obtained from 1) a digital frame camera, and 2) a LIDAR (Light Detection and Ranging) sensor system. These sensors function according to the logic shown in Figure 1. The change detection techniques include neighborhood correlation image analysis and single date elevation-based subsidence detection.

2.2 Remote Sensing Change Detection Process

Jensen (2005) reviews the general steps that are used to conduct change detection using remotely sensed data. The steps include 1) specifying the nature of the change detection problem, 2) identifying the remote sensing system and environmental considerations associated with change detection, 3) processing remote sensor data to extract change information by applying appropriate change detection techniques, and 4) evaluating the change detection results. Using these steps, scientists are able to decide whether their change detection results are of value. Selecting appropriate remote sensor data and change detection techniques according to the nature of the change detection problem under investigation is critical in change detection studies.

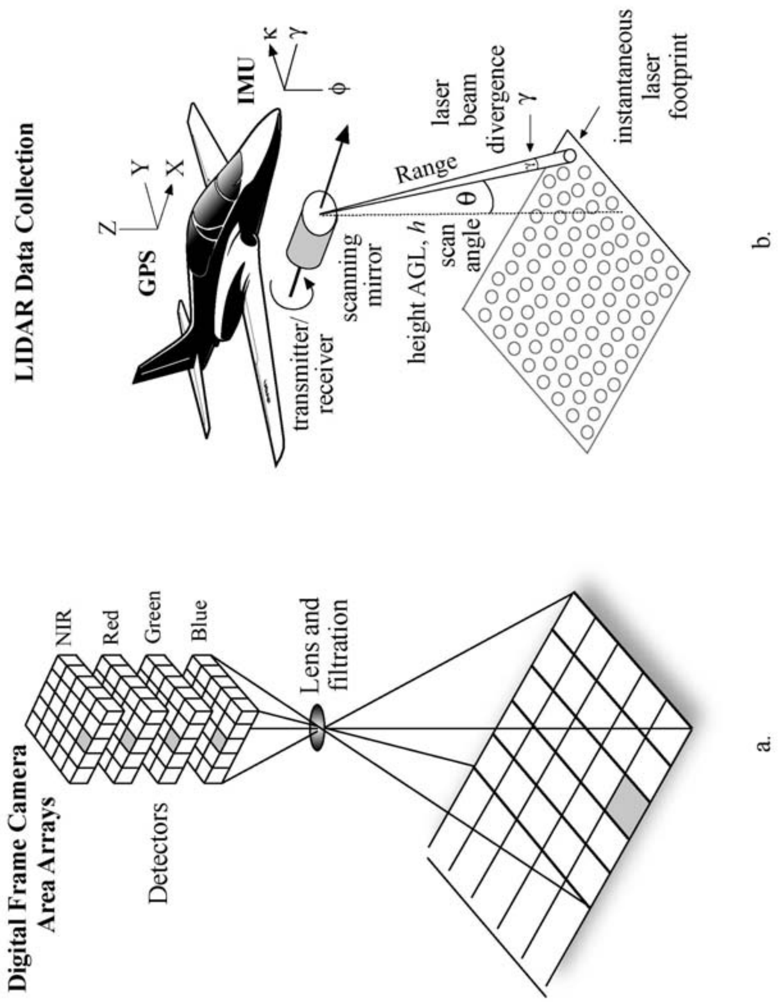

Fig. 1. Two remote sensor systems often used to collect information in the urban environment. a) Digital frame camera based on area arrays. b) LIDAR scanner.

2.2.1 Digital Frame Camera Remote Sensing

Digital frame cameras have many similarities to regular cameras. Instead of film, however, they use an area array of charge-couple-devices (CCD) detectors (Figure 1). Like a traditional camera system, the digital CCD area array records a “frame” of terrain during a single exposure. Three parameters determine the geographic area of the terrain recorded by the CCD area array, including 1) the dimension of the CCD array in rows and columns, 2) the focal length of the camera lens (the distance from the rear nodal point of the lens to the CCD array), and 3) the altitude of the aircraft above ground level (Jensen 2005). A major advantage of digital frame camera remote sensing is its timeliness. The remote sensor data are available as soon as they are collected since there is no need for an analog-to-digital (A to D) conversion.

2.2.2 LIDAR Remote Sensing

LIDAR is an optical remote sensing system that uses near-infrared laser light to measure the range from the sensor to a target on the surface of the Earth. Three fundamental technologies are used in the LIDAR system, including 1) laser range-finding, 2) differential global positioning system (DGPS), and 3) inertial measurement units (IMUs). LIDAR was initially introduced to facilitate the data collection for digital elevation models (DEM). Digital elevation information is a critical component of most geographic databases used by many agencies such as the USGS and FEMA. Digital elevation models can be subdivided into digital surface models (DSM) and digital terrain models (DTM). DSM contain elevation information about all features in the landscape, including vegetation and buildings. DTM contain elevation information solely about the bare-Earth surface (Jensen 2006). LIDAR technology can be used to generate the two types of elevation models.

Most LIDAR systems that are used for terrestrial topographic mapping use near-infrared light from 1040 to 1060 nm. Blue-green laser light centered at approximately 532 nm is used for bathymetric mapping due to its water penetration capability (Mikhail et al. 2001; Boland et al. 2004). Since LIDAR is an active system, it can also be used at night. The accurate measurement of the laser pulse travel time from a light transmitter to a target on the ground and back to a receiver is critical in the LIDAR systems. The range measurement process produces elevation data points, which are commonly referred to as masspoints.

One of the advantages of LIDAR remote sensing is that each LIDAR point is already georeferenced. It does not require additional geometric correction (Flood and Gutelius 1997). LIDAR systems receive multiple returns depending on the type of a target on the Earth surface. If a laser pulse hits directly on the ground, it will be recorded as a single return. If there are any materials (trees, grass) with local relief within the instantaneous footprint of a pulse, then the pulse will produce multiple returns (first, second … last returns). First returns including single returns can be used to generate a DSM, while last returns can be used to create a DTM. Additional processing is generally required to generate a DTM from last returns because some laser pulses never make it to the ground in heavily forested areas.

Most LIDAR systems provide intensity information in addition to the multiple return range data. The recorded intensity is in most cases just the maximum of the returned signals (Baltsavias 1999). The intensity values are dependent on several factors including gain setting, bidirectional effects, the size of the target, range to the target, angle of incidence and atmospheric dispersion (Leonard, 2005).

Neighborhood Correlation Image Analysis

The Neighborhood Correlation Image (NCI) analysis concept was introduced by Im and Jensen (2005). Correlation analysis can be applied to bi-temporal imagery in a specified neighborhood to extract spectral *contextual* information, which contains three unique variables associated with the change in two dates of imagery. These variables include neighborhood correlation, neighborhood slope, and neighborhood intercept. The neighborhood correlation variable represents Pearson's product-moment correlation coefficient between the brightness values from bi-temporal imagery in a specified neighborhood. The neighborhood slope and intercept variables are calculated using the least squares estimates from the sets of brightness values:

$$correlation = \frac{\sum_{i=1}^{n}\sum_{j=1}^{k}(BV_{ij1}-\mu_1)(BV_{ij2}-\mu_2)}{s_1 s_2 (n \times k - 1)} \tag{1}$$

$$slope = \frac{\sum_{i=1}^{n}\sum_{j=1}^{k}(BV_{ij1} - \mu_1)(BV_{ij2} - \mu_2)}{s_1^{\,2}(n \times k - 1)}$$

(2)

$$i\,ntercept = \frac{\sum_{i=1}^{n}\sum_{j=1}^{k} BV_{ij2} - a\sum_{i=1}^{n}\sum_{j=1}^{k} BV_{ij1}}{n \times k} \qquad (3)$$

where n is the number of pixels in a specified neighborhood, and k is the number of bands in each dataset. s_1 and s_2 are the standard deviations of the brightness values found in all bands of each dataset in a specified neighborhood, respectively. BV_{ij1} and BV_{ij2} are the ith brightness values of the pixels found in band k of the Date 1 and Date 2 images in a specified neighborhood, and μ_1 and μ_2 are the means of brightness values found in all bands of the Date 1 and Date 2 images in a specified neighborhood, respectively.

If the spectral changes of the pixels within a specified neighborhood between the two dates are significant, the correlation coefficient between the two sets of brightness values in the neighborhood will decrease to a lower value. The slope and intercept values may increase or decrease depending on the magnitude and direction of the spectral changes. Ideally, if there is no change in a certain pixel location between two dates, the pixel will have high correlation, a slope around 1, and an intercept around 0. An example of correlation analysis with two sample locations (change vs. no change) from bi-temporal ADAR digital frame camera imagery is shown in Figure 2.