MONITORING SUBURBAN SPRAWL USING HIGH RESOLUTION AERIAL IMAGERY: AN INTERACTIVE APPROACH

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1. INTRODUCTION

Recently, urban sprawl has generated national attention because of its effect on traffic, air quality, environment, and social and economic development. Caused mainly by technological advancement and population growth, urban sprawl in the past decades has been experienced at an unprecedented rate, predominantly in the form of suburbanization. Remote sensing and geographic information system (GIS) methods have shown promise as applications in mapping both historical and current land use and land cover patterns to study and monitor such urban/suburban sprawl (Tyler and Ginsberg, 1995; Green et al., 1994; Michalak, 1993; Kam, 1995; Bocco and Sanchez, 1995; De Brouwer et al., 1990; Li and Yeh, 1998). However, existing studies have focused primarily on large and medium metropolitan areas such as Washington, DC (Masek et al., 2000), Atlanta, Georgia (Yang, 2002), and Augusta, Georgia (Epstein et al., 2002). There are a few reports in the literature on the study of landscape dynamics and suburban sprawl in small urban areas with populations less than 100,000 in the United States. Furthermore, mapping urban sprawl with a combination of remote sensing and GIS methods have primarily focused on traditional maximum-likelihood classifiers, unsupervised classifiers, supervised classifiers, or change-detection algorithms using multi-temporal satellite imagery acquired from Landsat and SPOT to delineate new urban areas (Griffiths, 1988; Gong, 1993; Bruzzone and Prieto, 2000; Yang, 2002, Epstein, 2002; Chen et al., 2003). The spatial resolutions of Landsat (30-meter) and SPOT data sets (20-meter in multispectral mode, and 10-meter in panchromatic mode) provide very coarse land-use and land-cover information. The techniques discussed above may not be appropriate for monitoring suburban sprawl in small urban areas because they cover much less geographic extent compared to large or medium metropolitan areas. A better solution is to use high-resolution, multi-temporal aerial photographs, which provide sufficient land-use and land-cover information. With detailed land-use and land-cover information clearly shown in the aerial photographs, it is possible to develop an interactive approach to monitoring urban/suburban landscape change over time.

This paper presents the development of an interactive approach that utilizes multi-temporal and multi-scale high-resolution aerial imagery in a geographic information system (GIS) environment to visualize and analyze the suburban sprawl in Oshkosh, Wisconsin. The data sets for this study include black-and-white high resolution aerial photographs recorded from the early 1950s through the early 1990s, and ranging in scale from 1:20,000 to 1:40,000, as well as digital orthophotographs of 30-cm spatial resolution acquired in 2000. The medium and large-scale aerial photographs provide sufficient information for urban and suburban land use/land cover delineation and suburban landscape change visualization.

2. METHODOLOGY

2.1 STUDY AREA

Oshkosh is located in the east central Wisconsin. In the past half century, the city has noticeably experienced urban sprawl into surrounding agricultural land and wetland areas. The city of Oshkosh currently covers about 60 square kilometers in Winnebago County, Wisconsin, and hosts approximately 63,000 people (Census 2000). Although population growth is the main contributing factor for the suburban sprawl in Oshkosh, a series of new commercial, residential and business developments may also trigger the fast expansion of the city (Oshkosh Public Library, 2003). Examples of such development include: 1) the opening of Pioneer Inn in 1965; 2) the largest land annexation ever in Westhaven subdivision; 3) the expansion of the Whitman Airport for hosting the First Experimental Air Aviation Convention (world largest) in 1970; 4) the opening of Manufacturer Marketplace Outlet Mall; and 5) the opening of Mercy Medical Center in 2000.

2.2 DATA SOURCES AND PROCESSING

The data sources for the project include black-and-white aerial photographs, and digital orthophotographs. Black-and-white aerial photographs of the study area were recorded with standard 23- by 23-cm format mapping cameras by the Wisconsin Department of Transportation (WISDOT), the U.S. Department of Agriculture Aerial Photographic Field Office (USDA/APFO), and the U.S. Geological Survey (USGS) National Aerial Photography Program (NAPP). These air photos are primarily from the early 1950s through the early 1990s, and they range in scale from 1:20,000 to 1:40,000 (Table 1). Although they are black-and-white, the large-scale aerial photographs provide sufficient information for urban and suburban feature delineation.

TABLE 1
AERIAL PHOTOGRAPHIC COVERAGES OF THE STUDY AREA

Date	Format	Scale	Agency	Scanning resolution (dpi)	Output pixel size (m)
1950	23 x 23 cm	1:20,000	USDA/APFO	500	1.0
1957	23 x 23 cm	1:20,000	USDA/APFO	500	1.0
1971	23 x 23 cm	1:20,000	USDA/APFO	500	1.0
1981	23 x 23 cm	1:40,000	USDA/APFO	1000	1.0
1992	23 x 23 cm	1:40,000	NAPP	1000	1.0
2000	Digital mosaic	30-cm resolution	ECWRPC		

In the late spring of 2000, the East Central Wisconsin Regional Planning Commission (ECWRPC), in conjunction with Ayres Associates, Inc., generated black-and white digital orthophotographs for the east central Wisconsin region, including the study area. The digital orthophotographs are in the Wisconsin State Plane coordinate system (SPCS) central zone (zone number 4802), North American Datum of 1983 (NAD83) and provide 30-cm spatial resolution in digital format or 1:8,200-scale for hardcopy prints. The digital orthophotographs offer several advantages over the aerial photographs: (1) superior quality; (2) a current record of land-use patterns; and (3) already geo-referenced. Therefore, the digital orthophotographs are employed to geo-reference the black-and-white aerial photographs during the image-processing procedure.

The black-and-white aerial photographs of 1950, 1957, 1971, 1981, and 1992 were scanned with an EPSON XL386 scanner and converted to 8-bit (256 gray levels) data files. The scanning resolution varied depending on the original scale of the photographs and the desired output pixel size of the digital image (see also Table 1). For example, scanning a 1:40,000-scale photograph at a resolution of 1000 dots-per-inch (equivalent to 25 µm) produced a digital raster image of approximately1.0-m pixel size on the ground. The scanned aerial photographs were saved in uncompressed TIFF format and later imported to the Erdas Imagine (ERDAS, 2002) software package for image geo-referencing.

The detection of urban sprawl requires geo-referencing multi-temporal imagery using a common coordinate system, i.e., the Wisconsin SPCS. The image geo-referencing process entails the location of features that are easily recognized in both a digital raster image coordinate system (i.e., column and row) and a corresponding cartographic coordinate system (e.g., latitude and longitude, UTM, or SPCS). These features are referred to as image control points (CPs) and ground control points (GCPs), respectively. In areas of low to moderate relief, an affine transformation can be developed so that, for any given column/row location in the image, its corresponding cartographic coordinate can be estimated from a polynomial least-squares regression (first-order or second-order) (Lillesand and Kiefer 1987). The accuracy of the image geo-referencing can be examined using a root-mean-square error ($RMSE_{xy}$), a measure of the average total offset distance between all GCPs' predicted locations in a geo-referenced image and their true locations in a cartographic coordinate system based on the affine coordinate transformation model. It is a common practice to obtain RMSE values ranging from 0.5 to 1.0 pixel with adequate GCPs.

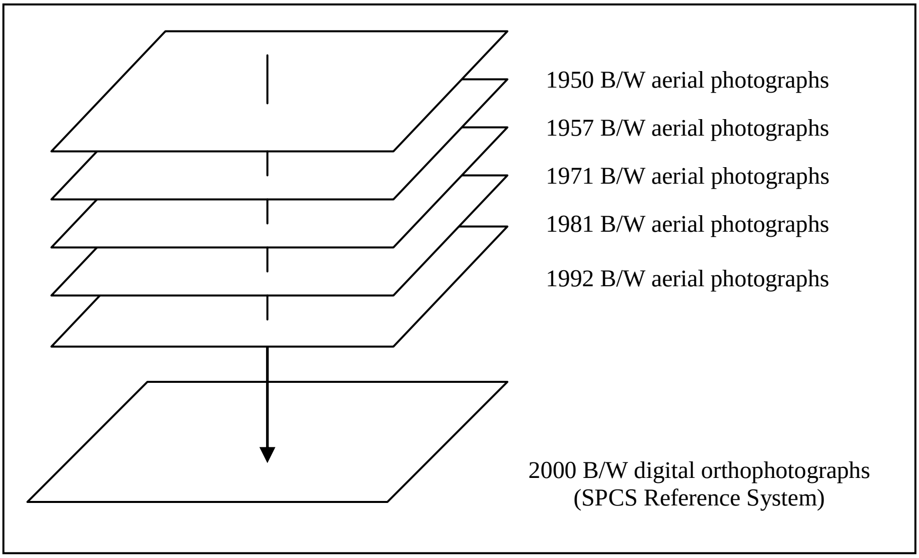
In this project, point features such as road intersections identified on the digital orthophotographs of 2000, that also are identifiable on the scanned black-and-white aerial photographs, were employed to establish GCPs for each scanned photograph. These GCPs were numbered, and their SPCS coordinates were obtained from the already geo-referenced digital orhtophotographs.

More than six GCPs were used to geo-reference each scanned photograph. The digital images of 1992 were geo-referenced first, followed by the digital images of 1981. Features shown on 1992 digital images served as GCPs for 1981 images if appropriate GCPs could not be found on the digital orthophographs. The digital images of 1957 were geo-referenced last. For each scanned photograph, a low RMSE was obtained during the image geo-referencing process, ranging from 0.5 to 0.7 pixel, and all image pixels were resampled to 1.0 m. After all scanned photographs were geo-referenced, they were ready to be used as data input for the development of the land-use and land-cover GIS database and suburban landscape change analysis and visualization (Figures 1).

2.3 DEVELOPMENT OF AN INTERACTIVE APPROACH

The purpose of the development of an interactive approach is to provide an easy tool for the analysis and visualization of suburban landscape change using the geo-referenced images of 1950s through 2000. This computer-based interactive system, developed on a Dell computer with 2.4 Gigabytes (GB) random access memory (RAM) running under the Windows XP operating system, consists of two components: a graphical user interface and a GIS application module. A graphical user interface, which includes a menu bar, a tool bar, map display windows, and a status bar, provides interaction between the user, the GIS application module, and the data sets. The graphical user interface was developed in Microsoft Visual Basic 6.0 through the use of menu editor, toolbar control, map control and status bar control functions.

FIGURE 1
REMOTE SENSING DATA FOR THE PROJECT INCLUDED THE BLACK-AND-WHITE AERIAL PHOTOGRAPHS OF 1950, 1957, 1971, 1981 AND 1992, AND THE DIGITAL ORTHOPHOTOGRAPHS OF 2000. THE LATTER FORM A GEOCODED MOSAIC TIED TO THE NORTH AMERICAN DATUM OF 1983 (NAD 83)



The tool bar contains a collection of button objects (e.g., Zoom in, Zoom out, Pan, Full extent, and Identify) that one can associate with a specific application. For instance, the icon with a plus sign ( ) is generally understood to represent a "Zoom In" function, and the icon with a hand sign ( ) represents a "Pan" function. A status bar is designed to display SPCS coordinate values for the location of the screen cursor within the image/vector display windows, and to show the display scale of the image/vector data.

The development of the GIS application module was implemented using Visual Basic and ESRI MapObjects 2.0 software. Visual Basic is state-of-the-art rapid application development (RAD) programming software that combines an interactive design tool and an object-oriented programming language (Microsoft 1999). In Visual Basic, extended capabilities can be added through the use of ActiveX custom controls (i.e., software components). This feature also permits companies to offer components with specific functionality tailored to applications such as GIS. Map control, toolbar control, and status bar control were used to develop the GIS application and graphical user interface, whereas text control, picture control, and time control were used to display multimedia information. The underlying relation among various custom controls was manipulated using Basic language.

MapObjects is an ESRI professional library of mapping and GIS software components for embedding spatial visualization and analysis in custom-written GIS applications. MapObjects includes an ActiveX custom control and a collection of over 35 programmable OLE (i.e., object linking and embedding) automation objects that allow developers to add mapping and GIS capabilities to applications developed within an application development environment such as Visual Basic (ESRI 1996). After loading MapObjects into Visual Basic as an ActiveX custom control, the image/vector data were added to map control (i.e., map display window) by writing code in Basic language. Then, GIS functions such as Zoom, Pan, Label and Identify were added to manipulate the image/vector data sets, as well as to query the GIS database.

3. RESULTS

Figure 2 is a composite map that displays the trend of suburban sprawl in Oshkosh between 1950 and 2000. The city covered 21.7 sq. km in 1950 and 60.5 sq. km in 2000, with annual growth of approximately 3.6%. This trend follows the same pattern as city population growth (Figure 3). The total population is 34,800 in 1950 and 62, 250 in 2000, with an annual growth rate of 1.6%. But, faster growth took place in Oshkosh in the 1970s and 80s when a large number of Hmong immigrants (approximately 1000) settled in Oshkosh and with the construction of State Highway 41. The latter resulted in the largest land annexation ever in 1966 at Westhaven subdivision located west of Highway 41, and attracted newer business development on both sides of the highway, including the Manufacturer Marketplace Outlet Mall which opened in 1994.

The computer-based interactive system offers the correspondent manipulation of the digital geo-referenced images of 1957, 1971, 1981, and 2000. When the application is running, it displays the four geo-referenced images in the four map display windows. By zooming and panning into one area in one of the four map windows, the other three will correspondingly display the same area with the same map scale. This provides the user an instant view showing where the urban/suburban landscape changes occurred over time.

Presented here is a series of screen-captured displays while running the application program. These displays reflect some historical moments in the development of the city in the past half-century. Figure 4 shows the landscape change near Pioneer Inn (labeled as 1 in Figure 2) which is shown on the scanned images of 1971, 1981 and 2000. The change is from wetland to commercial land. Figure 5 shows the on-going landscape change in Westhaven subdivision from the digital images of 1971 to 2000 (labeled as 2 in Figure2). The change is from agricultural land to suburban housing developments and recreational use (e.g., park, golf course). Figure 6 demonstrates the dramatic expansion of the Whitman Airport (labeled as 3 in Figure 2). Such landscape change can be seen clearly in the scanned image of 1971 aerial photograph. Figure 7 displays the landscape change at the Manufacturer Marketplace Outlet Mall (labeled as 4 in Figure 2). The original landscape is agriculture. Figure 8 displays the landscape change near the recently opened Mercy Medical Center (labeled as 5 in Figure 2). The original landscape is agriculture as well.

4. SUMMARY AND CONCLUSIONS

The interactive approach presented in this paper provides a new way to analyze and visualize suburban landscape change using high-resolution, multitemporal aerial photographs. The change analysis requires all aerial photographs to be scanned and geo-referenced to the same coordinate system. A computer-based system, developed in Visual Basic and MapObjects programming environments, provides correspondent manipulation of all or part of the multitemporal data sets interactively so the user is able to visualize and analyze the change. Without data generalization and classification, as most traditional change analysis techniques do, this new approach offers direct use of multi-temporal data sets, avoiding the long process to develop a GIS database. If incorporated with the traditional change-detection techniques that usually provide quantitative output, this interactive approach can improve the visualization of landscape change.

FIGURE 2
SUBURBAN SPRAWL OF OSHKOSH, WISCONSIN, 1950-2000

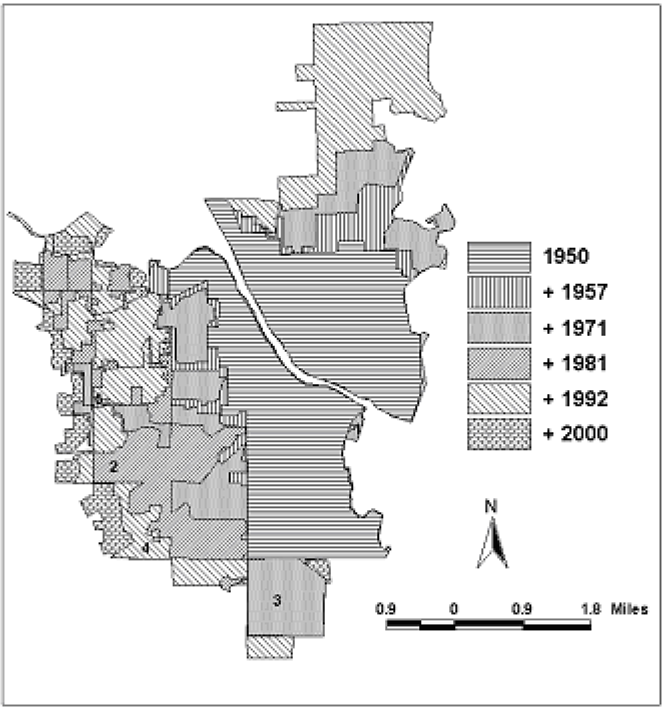


FIGURE 3
POPULATION AND TOTAL FLOOR AREA OF OSHKOSH, 1950-2000

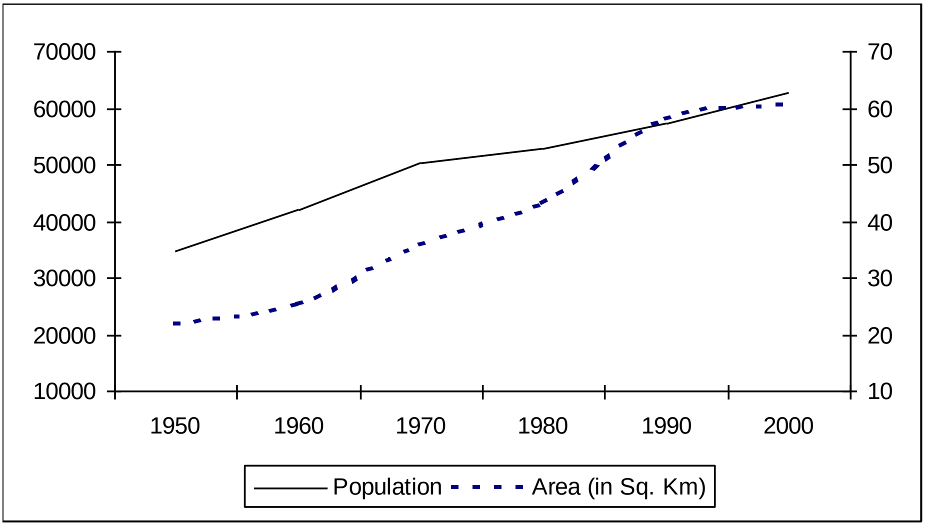


FIGURE 4
LANDSCAPE CHANGE NEAR PIONEER INN

FIGURE 5
LANDSCAPE CHANGE NEAR WESTHAVEN SUBDIVISION

FIGURE 6
LANDSCAPE CHANGE NEAR WHITMAN AIRPORT

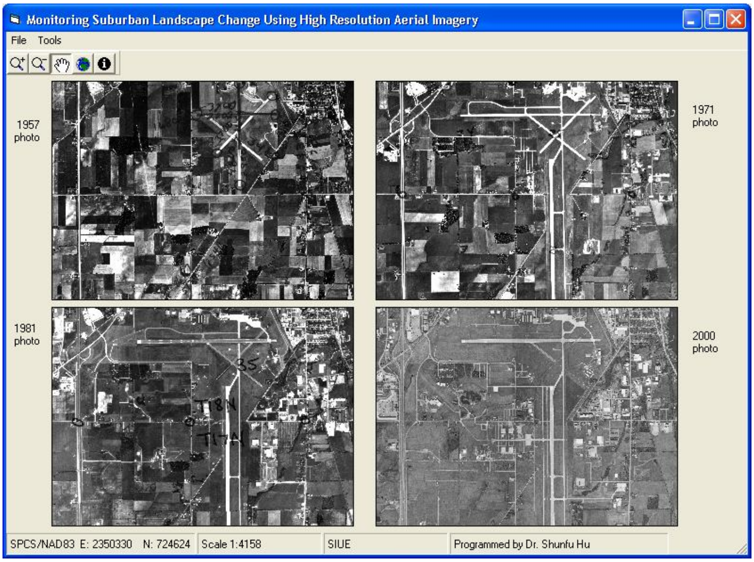


FIGURE 7
LANDSCAPE CHANGE NEAR THE MANUFACTURERS
MARKETPLACE OUTLET MALL

FIGURE 8
LANDSCAPE CHANGE NEAR THE NEW MERCY MEDICAL CENTER

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