Describing Urban Forest Cover

An Evaluation of Airborne Videography

Courtesy of USDA Forest Service

Airborne videography is conducted via a video capture system mounted in an aircraft such as this one.

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IN 1990, THE USDA Forest Service initiated the Chicago Urban Forest Climate Project (CUFCP) to better understand the effects of urban vegetation on the urban environment (McPherson et al. 1993, 1994). Through the CUFCP, new methods for investigating and quantifying the effect of trees on the urban ecosystem have been developed and examined (McPherson et al. 1994). As part of this effort, scientists have worked cooperatively with the Village of Oak Park; NASA's affiliate Space Remote Sensing Center (SRSC); and the Forest Service Forest Pest Management, Methods Application Group (FPM/MAG) to demonstrate the utility of two airborne videography systems compared to traditional aerial photography for interpreting urban land cover. Comparisons are made among the different types of imagery in terms of accuracy. Cost of imagery and implications for integration with geographic information systems (GIS) are also considered. The results are intended to identify the more useful and economical means for accurately describing urban forest cover.

CUFCP and other research findings have shown that urban forest structure (the characteristics, amount, and spatial arrangement of various urban land-cover types) is an important indicator of urban ecosystem functioning. Specifically, properly selected and located vegetation can function to moderate city temperatures, thereby conserving building energy use and reducing source power plant pollutant emissions (Akbari et al. 1989, Parker 1989); act as a sink for airborne pollutants (Bennett and Hill 1975, Smith 1984); reduce the amount and improve the quality of storm water runoff (Henson and Rowntree 1985, Sanders 1986); and offer other, less-quantifiable benefits such as opportunities for recreation (Dwyer et al. 1989) and wildlife habitat (DeGraaf and Wentworth 1986, Stearns 1972).

The opportunity for trees and other vegetation to provide these environmental services is partially determined by the extent and distribution of the vegetative cover within an urban land matrix. For example, trees adjacent to homes are better situated to enhance energy use efficiency than isolated rows of trees along highways. The relative amount of tree cover in a given area is described by the available growing space (AGS) and canopy stocking level (CSL). The AGS is the area of land in tree, shrub, grass, bare soil, or other plantable cover type. It suggests the potential for city trees to shade buildings and lower air temperatures, intercept airborne pollutants and precipitation, and provide other environmental services. The CSL is the percent of AGS currently in tree canopy and, along with descriptions of canopy distribution, can be used in benefit-cost analysis to estimate the environmental services existing trees provide. Knowing tree cover distribution and extent is additionally useful because different agencies and individuals manage city trees in residential, commercial, and publicly owned areas.

Measures of vegetative cover and the spatial arrangement of trees and other cover types suggest a direction for planning efforts and help set management priorities. In a broader sense, tracking the quantity and distribution of tree and other urban cover types over time can be used to monitor urban forest change and develop an ecosystem approach to urban forest management. City trees are a component of the flow of materials and energy constituting the urban ecosystem that can be intentionally managed to improve the quality of life in cities now and in the future (Rowntree et al. 1994).

An Emerging Technology

Airborne videography, the acquisition and processing of remotely sensed data from video systems mounted in a fixed-wing air-

Table 1. Land-cover classes.

Land-cover type	Description
Tree/shrub	Grouped or single trees and large shrubs
Grass/soil	Areas of soil, grass, and other vegetative ground cover
Building	All types of permanent and temporary structures
Paving	All artificial paving materials; brick, concrete, asphalt, etc.

craft, has emerged as an alternative to aerial photography for gathering information on land cover characteristics. However, work with airborne videography generally has been conducted in the management and research of agricultural and natural forest systems. In urban areas, it is untested.

Traditionally, aerial photographic interpretation is used to describe land cover in urban areas (Rowntree 1984, Nowak et al. 1995). Interpretation frequently employs the use of random point sampling to describe relative amounts of cover within particular cover classes (Wilson 1960). Aerial photographic interpretation has the advantage of providing a historical record for an area, but photo processing, interpretation, and map production can be time consuming and costly (Myhre and Silvey 1992). Because such photographs are generally used by planners and engineers concerned with urban infrastructure, they are usually leaf-off, making tree cover analysis difficult.

Airborne video also has certain advantages as a remote sensing tool. Because video cameras have higher light sensitivity than film cameras, greater spectral accuracy is obtained with the use of narrow band filters compared to traditional aerial photography (Bartz et al. 1992). Other advantages of airborne video include the ability to view imagery as it is collected and make necessary corrections in-flight, quick and inexpensive image processing, and direct integration into GIS (Bartz et al. 1992). However, start-up costs for equipment, software, and training can be costly, and spatial resolution of video imagery can sometimes be poor.

Airborne video systems include one or more video cameras mounted in a small aircraft, a video monitor for in-flight monitoring, a video recorder or digitizer, navigation equipment, and a caption generator to overlay location coordinates and time. Recent technological advancements in video imaging systems have improved image quality, affordability, and portability (Myhre and Silvey 1992).

Digital and analog airborne video systems have been developed to monitor plant health and obtain vegetative inventories on national forests, agricultural lands, and riparian areas. Analog information is stored and processed as a continuous variable, like signal intensity, while digital information is numerical and discrete. Digitizing is the conversion of analog information to digital data. The digital multispectral video system developed by SRSC has been shown to provide rapid data processing and information delivery to farmers in central Wisconsin, allowing assessment of hail damage, irrigation stress, and crop maturity within narrow biological windows (Pearson et al. 1993). The SRSC multispectral video system has been shown by Weih and Tappe (1995) to be superior in spectral resolution to Landsat, Spot, and scanned aerial photography. The Forest Service has used analog composite color airborne videography to monitor forest and individual tree health (Frament et al. 1992), verify satellite data, supplement existing GIS databases (Evans and Beltz 1992), document timber trespass, survey road maintenance, and assess stream channels (Bergey 1992). Bartz et al. (1992) found that video applications in less intensely managed areas, such as riparian ecosystems, provide inexpensive and timely cover-type assessment.

Table 2. Land-use classes.

Land-use type	Description
1- to 3-family residential	Predominantly 1-, 2-, and 3-story residential
Greater than 4-family residential	Predominantly apartment buildings and condominiums
Industrial/commercial	Small shops, strip and large malls, and business and manufacturing centers
Institutional	Hospitals, schools, libraries, and other public facilities
Transportation	Highways and railroads
Park	Open space with some forested areas like forest preserves, golf courses, and parks

Procedure

To test the application of airborne videography in urban areas, Oak Park, Illinois, was selected as a case study. Oak Park encompasses 4.5 square miles in Cook County, immediately west of Chicago, and is within the CUFCP study area. Oak Park officials have a complete inventory of all public and private trees and are integrating this database into a GIS. This study compared SRSC multispectral digital color video, FPM/MAG Super VHS format analog composite color video, and black-and-white and color infrared photography of Oak Park.

Digital, analog, and photographic systems for acquiring and processing various types of imagery each use different procedures, software, hardware, and equipment They were employed as they exist and were available without modification for this project so that comparisons among them would be more relevant to potential users However, the demonstration project did aim for a consistent and uniform method for interpreting and comparing imagery produced by each system.

Ground Verification

In June and July, 1993, a team of two field workers visited 365 plots to provide a ground verification reference to compare the various types of imagery. Points were systematically located on the black-and-white aerial photos using random techniques. Each point marked a plot location The photos were then taken into the field to locate plots and classify them for land use and land cover. The field workers defined plots as the area outside but adjacent to the north edge of the point on the aerial photo Plot dimensions were defined by the area that would be immediately "underfoot" if the field worker were standing at this location, whether it was on top of a building, tree, or other cover type. Land-cover classes, defined in *table 1,* were identified as the predominant cover type in the plot. Classifications of land use, described in *table 2,* were based on the predominant characteristics of the area surrounding the plot.

Image Acquisition

Aerial photography. Black-and-white aerial photography of Oak Park taken in March 1992 was obtained at a scale of 1:4,800 (1 inch=400 feet) on two photographic paper prints from a commercial remote sensing firm. Because leaf-on color infrared imagery did not exist at a reasonable scale for the site, a special flight was conducted in September 1993, producing two 9-inch by 9-inch color infrared photographs at a scale of 1:15,600 (1 inch = 1,300 feet) on photographic print paper. Resolution of either type of photography was not determined because of the difficulty in accounting for variables affecting resolution such as film characteristics and image degradation.

Airborne videography. In June 1993, five flight lines of analog color and digital video imagery were obtained. The FPM/MAG analog video system was flown at about 5,900 feet above mean ground level with a single color video camera with the lens set at 20 millimeters. This produced a half-mile wide swath of ground coverage and pixel dimensions of 6.5 feet on a side. The SRSC system is most notably different from the FPM/MAG system in that it uses three cameras to collect three bands of data simultaneously in digital format and saves the data in-flight on a personal computer. The SRSC digital video system with red, green, and infrared cameras gathered more than 300 video frames, one frame digitized every 1.5 seconds, from about 5,100 feet above mean ground level, giving pixel dimensions of 4 feet on a side. The different pixel dimensions, or resolution, between the two types of video imagery resulted from differing altitudes and acquisition system characteristics. Components of both systems are listed in *table 3.*

Image Processing

Analog. The analog color video was viewed in the office to select individual frames for digitizing as 16-bit composite color raster images using map and image processing system (MIPS) software. To eliminate vignetting during mosaicking, 55 frames were required, providing a 25% to 30% overlap between adjacent frames. Vignetting is a darkening at the edges of an image created when a lens passes more light to the center of an optical field than to the edge. Using MIPS, each frame was digitized and mosaicked into flight line subsets by locating ground control points. The mosaicked flight line was then georeferenced with scanned US Geological Survey maps (7.5 minute quadrangles).

Digital. Using both automated and manual procedures, video frames digitized in-flight were selected to allow about 20% overlap to eliminate vignetting. These frames were then mosaicked together and georeferenced using Earth Resources Data Analysis System (ERDAS) and Science and Technology Laboratory Application Software (ELAS).

Image Interpretation

Researchers employed a consistent, uniform method for interpreting the various types of imagery, which has been used for aerial photographic interpretation and was adapted here for the video imagery. Each point first located on the black-and-white photography and then ground verified by the field crew was assigned a unique identification number. The points were then carefully transferred to the same locations on the color infrared aerial photography and on individual frames of both types of videography. Using the land-cover and use categories from *table 1* and *table 2* respectively, two interpreters classified. More than one interpreter was used in an effort to diminish the effect of individual interpreter bias. As in the ground verification, interpretations were made for the area outside but adjacent to the north edge of the point that would be immediately "underfoot" if the field worker were standing at this location. The results were compiled into a series of tables listing for each point the land use and land cover interpreted on each type of imagery as well as the points' ground verification.

Comparison of Imagery

The analog and digital videography and the black-and-white and color infrared aerial photography were compared by analyzing the accuracy of interpretations. Accuracy was estimated in two ways using averages from the two interpreters. First, the percent land cover and land use interpreted from each type of imagery was compared to the percent obtained from the ground verification. Then, the percent of correct individual point classifications was determined by comparing cover classifications for each point to the ground verification for that point. The ground verification serves as the best estimate of the true land use and land cover for the point.

Table 3. Video acquisition system components.

Digital system	Analog system
Three digital cameras with 8-mm lens and green, red, and near infrared filters	Super VHS video camera with a 9.5-mm–143-mm zoom lens and camera mount
Onboard video monitor, GPS, and computer system	Onboard video monitor
Caption generator and navigation equipment	Caption generator
Three-band digital output to 8-mm exabyte tape	Color composite output to portable Super VHS tape recorder

Results

Comparison of imagery. Table 4 shows land-cover class percentages from the different types of imagery compared to land-cover percentages determined from the

Table 4. Percent land cover interpreted from imagery compared to ground verification[1].

Cover class	Ground verification	Black-and-white photo	Color infrared photo	Analog video	Digital video
Tree/shrub	43.0	25.1 (–17.9)	41.4 (–1.6)	33.8 (–9.2)	34.4 (–8.6)
Grass/soil	11.2	21.5 (10.3)	13.0 (1.8)	15.3 (4.1)	14.6 (3.4)
Building	24.9	28.1 (3.2)	24.0 (–0.9)	25.8 (0.9)	25.8 (0.9)
Paving	20.9	25.3 (4.4)	21.6 (0.7)	25.1 (4.2)	25.2 (4.3)
Available growing space	54.2	46.6 (–7.6)	54.4 (0.2)	49.1 (–5.1)	49.0 (–5.2)
Canopy stocking level	23.3	11.7 (–11.6)	22.5 (1.2)	16.6 (–6.7)	16.9 (–6.4)

[1]*Percent cover and difference in percent cover ( ) from ground verification.*

ground verification. Overall, the most accurate cover estimates were obtained from the color infrared photos, in which the greatest difference from the ground verification was only 1.8%. The next most accurate percent land-cover estimation was with the digital and analog video, in which the greatest difference from the ground verification was 8.6% and 9.2% respectively. Least accurate was the black-and-white aerial photography, with a difference of up to 17.9% from the ground verification values.

Accuracy was also measured as the percent of individual points classified correctly compared to the ground verification. That is, the land-use and land-cover classification for a particular point was tallied as either correct or incorrect compared to the ground verification for that point. Findings are expressed in *table 5* as a percentage of points correctly interpreted. Accuracy of land-use interpretations ranged from 79% to 91% correct, relatively high compared to land-cover interpretations. Tree/shrub cover was most correctly interpreted with color infrared photos (69.8%), followed by digital video (64.5%) and analog video (62.6%). Interpretations of tree/shrub cover from black-and-white photos were least correct (46.4%). In all cases, tree/shrub cover was most frequently misinterpreted as grass or paved cover *(table 4)*.

When results are viewed across all types of imagery, paved and built surfaces had higher percentages of correct interpretations (61.6%–79.4%) than did estimates of other land cover. With the exception of black-and-white photography, grass/soil was the least accurately interpreted type of land cover. Overall estimates of AGS should be fairly accurate for most types of imagery because most misinterpretation involves trees as grass and grass as trees. However, estimates of CSL will reflect interpretation of tree/shrub and some grass/soil cover.

Expenditures for either of the two types of aerial photography or videography depend on the availability of existing imagery and acquisition and processing systems. Existing black-and-white photography is often available, but existing high altitude color infrared photography is generally not useful because of low resolution. However, contractors will fly missions to obtain black-and-white or color infrared aerial photography. Generally, cost for color infrared transparency film and processing is 20% greater than for black-and-white. Video imagery can be procured through cooperative agreements with federal or private agencies. A complete image-processing hardware and software system required for the analog color video can cost $10,000 or more depending on the system's configuration. Interpretation of the nearly 365 ground verification points on each type of imagery for land use and cover classes required about 1 to 3 hours. Considerations regarding time and money required for image acquisition and processing of the 4.5 square miles of Oak Park are listed in *table 6*.

Table 5. Percent of points correctly interpreted on imagery.[1]

Cover class	Black-and-white photo	Color infrared photo	Analog video	Digital video
Tree/shrub	46.4 (G)	69.8 (G, P)	62.6 (G)	64.5 (G, P)
Grass/soil	56.9 (T)	45.6 (T)	37.5 (B)	49.3 (T)
Building	79.4 (P)	68.1 (T)	61.7 (P)	70.8 (P)
Paving	65.4 (B, G)	61.6 (G)	68.0 (B, G)	66.7 (G, B, P)

[1]Most frequent reason for misinterpretation is indicated within ( ), where B=building; G=grass; P=paving; T=tree.

Discussion

The intent of this study was to make the results of various measuring systems more relevant to potential users, who may not have the resources to create or modify these technologies. Consequently, parameters like scale and resolution vary across the types of imagery and may affect the level of accuracy measured.

For overall estimates of percent cover, photography and videography are both fairly accurate and useful. Percent cover estimates using the color infrared photography achieved the greatest accuracy. However, both videography and aerial photography underestimate overall percent tree cover and overestimate other cover types Although misinterpretations associated with different imagery have a minor effect on estimates of available growing space, they can adversely affect the accuracy of canopy stocking level.

Comparing the interpretation of each individual point to its ground verification reveals a noticeably low percent of accuracy across all types of imagery. In terms of correctly interpreted points, color infrared, leaf-on photography provided the most accurate (69.8%) estimate of tree cover. Although black-and-white leaf-off photography allowed the greatest accuracy in identifying grass and building cover (56.9% and 79.4% respectively), interpre-

Table 6. Time and cost considerations for photography and videography of Oak Park, Illinois.

Activity	Analog video[1]	Digital video[1]	Black-and-white photo	Color infrared photo
Acquisition				
Mission planning and flying	2 to 3 days, plus about $1,000 aircraft cost		$116 (9 photos)	$1,000 (5 photos)
Processing				
Film processing[2]	N/A	N/A	Included in cost listed for acquisition	
Digitizing	1 day	Included in acquisition	N/A	N/A
Mosaic/rectify	3 days	7.5 days	N/A	N/A
Interpretation[3]				
About 365 points	2.5 hours	2 hours	2 hours	1.5 hours

[1]Actual acquisition cost figures are not shown for the two video techniques as some of the time and materials were donated for this pilot test. Processing/interpretation estimates do not reflect time for training.

[2]One- to three-week wait unless already available.

[3]Average time from two interpreters.

tations were least accurate when identifying tree cover (46.4%).

Analog color videography allowed the most accurate interpretation of paved areas (68%) but made identification of grass difficult (37.5%). Like color infrared photography, the digital video system used is sensitive to infrared light, which is suitable for distinguishing vegetation. It allowed the second most accurate interpretation of tree cover (64.5%).

Possible sources of error of interpretation include differences in scale, resolution, and imagery acquisition date, as well as omission of trees due to leaf-off imagery. For example, trees planted after the date of the black-and-white photographs (1992) could have been surveyed on the ground but not observed on the photos. The edge of deciduous tree crowns is difficult to observe in leaf-off imagery and can cause misinterpretation of tree cover as the cover type underneath the crowns.

Another source of error is interpreter bias, which was minimized by using two interpreters. A study comparing color infrared aerial photographs and satellite imagery of Syracuse, New York (Sadowsky et al 1987), demonstrated that interpreter bias can be substantial. Agreement among interpreters regarding the aerial photography of Syracuse was approximately 80% with three cover-type classes and 52% with eight cover-type classes. Agreement was substantially lower on the satellite imagery at both levels of detail. The relative inconsistency among interpreters was attributed to the spatial complexity of urban areas and subjectivity associated with interpreting urban land cover.

Investments of money and time required for acquisition and processing of imagery varied. Both forms of aerial photography are priced similarly but involve lengthy photo processing. However, leaf-off black-and-white photos are often readily available and relatively inexpensive. The analog color videography required less time for processing than digital video and had the additional advantage of being available for viewing immediately on landing.

Although the actual costs for each type of imagery used in this study have not been listed because some time and materials were donated, costs can be estimated by applying an hourly rate to the time data in *table 6*. Assume that $40 an hour would be the average rate for payroll, benefits, and overhead between a project manager and technician. Multiplying $40 by hourly time estimates derived from *table 6*, adding $1,000 in aircraft cost for the videography and the cost for the aerial photos gives a total of $2,340 for the analog video; $3,640 for the digital video; $196 for the black-and-white photography; and $1,060 for the color infrared photography. These figures do not include all materials costs or the cost of obtaining a video acquisition system (transportation or purchasing) and processing system (hardware and software). They do reflect at least the relative investments of time and money for each type of imagery as used in the study.

A GIS offers certain analytical tools, like cover-type classification and vegetation indices for describing plant health or genera. Because it is relatively simple to transfer video imagery into a digital format for use in a GIS, it may be preferable to use a GIS for video imagery analysis over the manual interpretation of random points common to aerial photo interpretation. To use video imagery or aerial photography in a GIS it must first be digitized in frames or sections and then pieced together with image processing or GIS applications. Digitizing, rectifying, and mosaicking photography or videography requires substantial investments of time and money for training and equipment.

Findings from this study suggest that careful consideration be given to the accuracy of urban land-cover assessments using remotely sensed imagery. Fairly accurate estimates of overall land-cover and land-use percentages are obtained using the procedures and types of imagery reviewed in this study, but accurate classification of individual points is not achieved. Among the forms of remotely sensed imagery examined here, color infrared aerial photography offers the highest degree of accuracy and, considering the limited availability of airborne videography systems and their costs, may offer a better tool for urban forest managers and planners interested in urban land cover, particularly trees. However, with further advances in video system technology and reductions in time required to mosaic video imagery, airborne videography may become a viable alternative to traditional methods for describing land cover in urban areas. JOF

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