Airborne Videography: Current Status and Future Perspectives

P. W. Mausel
Department of Geography and Geology, Indiana State University, Terre Haute, IN 47809
J. H. Everitt and *D. E. Escobar*
USDA-ARS, Remote Sensing Research Unit, Weslaco, TX 78596
D. J. King
Department of Geography, Carleton University, Ottawa, Ontario K1S 5B6, Canada

ABSTRACT: Airborne videographic remote sensing is less than a decade old. Its recent growth at the USDA-ARS at Weslaco, Texas and selected universities is evidence of a plethora of research and applications in this field. Video imagery, when interpreted by visual or computer techniques, has provided insights into a variety of Earth features. Much research has been done on detecting and assessing variables relating to cropland, rangeland, tree crops, and soils. In addition, videographic research and its applications have been conducted in forestry, water quality, wetlands, land-cover inventory, and urban land use. The poorer resolution of video compared with film has limited some applications, but the numerous advantages of videography have promoted its increasing use. In the future, advances in video technology will result in improved spatial resolution suitable for expanded applications.

INTRODUCTION

Airborne videography as a remote sensing tool has greatly expanded during the past five years, although a sustained interest in using video cameras for remote sensing has existed for a decade (Manzer and Cooper, 1982; Edwards, 1982; Escobar et al., 1983; Vlcek, 1983; Everitt et al., 1991a). The acknowledgment of videography as a vital element in remote sensing was evidenced by addition of the term videography in the title of the 1987 ASPRS' Eleventh Biennial Workshop on Color Aerial Photography and Videography in the Plant Sciences, and by the ASPRS-sponsored First Workshop on Videography in 1988 (Mausel, 1988).

Video has many characteristics that make it a sensor of choice or an equivalent system for use in selected applications (Nixon *et al.*, 1985; Richardson *et al.*, 1985; Vlcek and King, 1985; Everitt *et al.*, 1986; Stutte *et al.*, 1990). Among its advantages are

- low cost,
- real-time or near-real-time availability of imagery for visual assessment or computer image processing analysis,
- immediate potential for digital processing on the signal,
- ability to collect spectral data in very narrow bands (5 to 12 nm) in the visible to near infrared (NIR),
- ability to collect spectral data in the mid-infrared (1.35 to 2.50 μm) water absorption regions, and
- data redundancy in which images are acquired every 1/30 second producing multiple views of a target or scene.

The major disadvantage of video imagery is its relatively low resolution when compared to film. Standard video recorders have an image resolution of 240 (color) and 300 (black-and-white/B&W) lines across the format fields in comparison to the potentially more than 1500-line resolution of 35-mm slide film. However, the Super-VHS (S-VHS) recorder offers 400-line resolution (Lusch, 1988) and ultimately it may be technically possible for video resolution to approach that of 35-mm film. Difficulty in calibrating video data often has been cited as a problem because without calibration, scene-to-scene comparisons and multitemporal analysis are not possible. However, research has been conducted to help alleviate this problem (Richardson *et al.*, 1992).

IMAGE ANALYSIS

An overview of video systems used in contemporary videography and selected examples of research and applications are given in this paper. With the exception of the digital camera, the video cameras described herein generate a National Television System Committee (NTSC) standard signal which permits their use with any standard video recorder and TV monitor.

Analysis of raw video data varies greatly with the analyst and type of research or application. Some video researchers use basic visual interpretation of B&W or color composite images. Color imagery is often used for general land-cover feature interpretation and to some extent for image analysis. Videographic research and applications often implement digital image processing to analyze, quantify, and classify narrow-band multispectral images, in both original and transformed data formats (e.g., ratioing, principal components, and texture) (Everitt *et al.*, 1988b; King and Vlcek, 1990; Mausel *et al.*, 1990; Yuan *et al.*, 1991).

Analyzing video data, particularly multispectral, varies from simple to complex. Each user has his/her own approach to acquire and process video data for research and/or applications. However, the visual and/or computer techniques used in videography are generally similar to techniques used in other types of remote sensing. Examples of the common video systems and selected applications associated with them will be given to provide insight into the nature and breadth of contemporary videography.

VIDEO SYSTEMS AND SELECTED APPLICATIONS

This section provides a crossection of types of video systems which have been used extensively. A summary of selected advantages and disadvantages for types of systems is found in Table 1.

Single Band Systems

Initially, videography research was conducted using single B&W tube-type cameras (18-mm sensor format size) which had visible (0.4 to 0.7 μm) or visible/NIR sensitivity (0.4 to 0.8 μm). These early systems were used to evaluate potato blight (Manzer and Cooper, 1982), plant leaf radiation (Gausman *et al.*, 1983), and freeze-damaged citrus (Edwards, 1982; Escobar *et al.*, 1983).

Multipleband Video Camera Systems

A majority of current videography researchers have taken advantage of systems designed to generate multiband data which

0099-1112/92/5808–1189$03.00/0

TABLE 1. ADVANTAGES AND DISADVANTAGES OF SELECTED VIDEO SYSTEMS.

System	Advantages	Disadvantages
Single Camera (Panchromatic)	Low Cost (<$5,000) Easy Operation Very Portable Familiar Image Product	Broadband Data Single Band Analysis (Limited Applications) Less Suitable for Computer Processing
Single Camera (Color)	Low Cost (<$5,000) Easy Operation Portable Familiar Color Image Product	Not Versatile (Limited Applications) Broadband Data Less Suitable for Computer Processing
Multispectral Systems		
Biovision	Most Similar to Standard Video Low Cost for Advanced Technology (<$15,000) Portable Minimal Training Required	Image Lag (fuzzy) Broadband (100 nm) Fixed Spectral Bands Somewhat Limited Applications
Xybion	Single CCD (Alignment Not Necessary) Up to Six Selectable Bands Narrow Bandwith (10 nm) Good Research System Portable Minimal Training Required	Band Translation Problems (Aircraft Motion Related). Moderate Cost (>$15,000) Vignetting in Older Models
Multicamera Systems	Flexibility (Aperture, Not Necessary) Color/False Color Imagery Simultaneous Viewing of Several Bands Narrow Bandwidth (10 nm) Good Research Systems	Difficult Camera Alignment Image Translation Problems Possible Multiple Recorders/ Monitors Needed Bulky/Heavy Moderate to High Cost (>$30,000)

have a greater potential for deriving information overall than do single band systems. These systems, many of which are discussed below, may utilize one or more cameras, but in all cases, more than one band of spectral data can be acquired from the system operation.

Color Camcorders

Normal color (0.4 to 0.7 μm) VHS and S-VHS camcorders with 13-mm or 18-mm format size solid state CCD sensors have been utilized in various applications. For example, this system was used for mapping soils (Gerbermann *et al.*, 1988) and detecting of saltcedar (*Tamarix chinensis* Lour.) infestations (Everitt *et al.*, 1990a). Maggio *et al.* (1989) used color video to determine areas of forest cutovers and monitored restocking programs. Ehlers *et al.* (1989) used a high resolution CCD camera to acquire detailed forest data used within a GIS context to update forest maps.

*Biovision Color Infrared System**

This system is a professional-grade, three-tube color, single-lens camera designed to simulate color infrared (CIR) film (Meisner and Lindstrom, 1985). It has an internal optical beam splitter with dichroic mirrors that focus Green (G), Red (R), and NIR radiation onto three 18-mm video tubes which are simultaneoulsy scanned. Output of these three bands is in separate blue (B), G, and R channels, respectively. The Biovision system has been used in many agricultural applications (Meisner and Lindstrom, 1985), as well as for mapping of forest insect pests (Lusch and Sapio, 1987; Myhre *et al.*, 1987) and wetland communities (Mackey *et al.*, 1987).

Lusch and his associates are now using this system in yearly applications for evaluation of Gypsy Moth impacts on Michigan forests after previously identifying its potential for this purpose in research. Wu (1988) used the Biovision camera in close-range studies to determine size, density, and spatial distribution of leaves, branches, and trunks of various trees. Airola (1989) reconstructed patterns of forest destruction related to arsenic contamination.

Xybion System

Xybion is a commercially available high quality and versatile B&W single solid-state camera system which can collect up to six bands of data in rapid sequence using a rotating filter wheel. The video camera is integrated with a microprocessor-based digitizer with programmable resolution. This system has been used in a variety of agricultural and rangeland applications which often use transformed and original data within sophisticated image processing systems to maximize information extraction (Ammon *et al.*, 1987; Beck *et al.*, 1988). The MSC-02 camera, with bands comparable to Landsat TM, is being used to establish relationships between key water parameters and spectral responses in order to help establish a quantitative water resources monitoring system (Bacheri and Stein, 1992).

USDA-ARS B&W Multi-Video Camera System

The limitations associated with a single camera system were rectified by USDA-ARS researchers from Weslaco, Texas, who initially developed a system comprised of four nonsynchronized video tube cameras (18-mm tube), each with a Betamax recorder (Nixon *et al.*, 1985). Each camera had different filters which provided four user-designated bands to be acquired. This system was used to differentiate weeds from selected grain and vegetable crops using a supervised classification approach (Richardson *et al.*, 1985) and it was used to develop video-based vegetation indices (composite images) for assessment of grass phytomass production (Everitt *et al.*, 1988b). Their system was also used to assess various rangeland parameters (Everitt and Nixon, 1985).

USDA-ARS False Color Multispectral Imaging System

Although the initial USDA multicamera system worked well for a variety of research purposes, it lacked the capability to generate color imagery. Therefore, a second system was developed in a cooperative effort between UDSA-ARS and the Southwest Research Institute at San Antonio, Texas, which provided both multispectral B&W and color composite imagery. The system consisted of four B&W tube-type cameras — three visible (0.4 to 0.7 μm) and one visible/NIR camera (0.4 to 1.5 μm), each equipped with narrow-band (9 to 12 nm) filters. An encoder was integrated with the cameras to provide false color composite imagery which, along with individual B&W bands, were recorded on Betamax recorders/players. The system is described by Nixon et al. (1987).

This system was initially used for detection of root rot in cotton, detection of excess soil moisture, and assessment of the performance of subsurface soil drain tile systems (Nixon *et al.*, 1987). Hart *et al.* (1988) detected sooty mold deposits and chlorosis on citrus trees and also evaluated the overwintering habitat of the boll weevil. Everitt *et al.* (1988a) detected soil salinity problems in agricultural and rangeland areas, and used image processing techniques to quantify their extent. Mausel *et al.*

* Trade names are included for the benefit of the reader and do not imply an endorsement of or a preference for the product listed by the authors.

(1990) showed that multispectral video data were highly correlated with soil color and organic matter content. Color-infrared video imagery also showed potential for assessing grass vigor and grazing intensity, distinguishing severely eroded native rangeland (Everitt *et al.*, 1987b), detecting weed infestations on rangelands (Everitt *et al.*, 1990a), and distinguishing among rangeland plant communities (Everitt et al., 1990b). Lulla *et al.* (1987) used multispectral narrowband data in the form of three common vegetation indices to discriminate successfully among vegetation types in a rangeland environment. Mausel *et al.* (1991) found correlations with water secchi depth, and Repic *et al.* (1991) showed that video data correlated with ferrous ion content in polluted surface mine water.

USDA-ARS High Resolution Multispectral Video System (HRMVS)

The Weslaco USDA-ARS original false color multispectral system was modified and improved with new components which optimize high resolution imagery (Everitt *et al.*, 1991b). It uses three B&W high resolution cameras (0.4 to 1.1 μm), equipped with narrow-band filters that have 565 horizontal line resolution, and a professional grade S-VHS camcorder (0.4 to 0.7 μm) with 400 horizontal line resolution. A color encoder and four professional S-VHS recorders complete the configuration. A camcorder, an optional camera in the system, acquires conventional color imagery and is not synchronized with the other cameras, but records the same field of view.

This HRMVS is being tested for a variety of purposes such as comparison of its CIR video imagery capabilities to conventional CIR photography. The CIR video version is not as sharp as film, but its quality is good; when combined with the other advantages of videography, it may serve as a substitute for film in some applications. USDA-ARS scientists have used the HRMSV CIR imagery (visual and/or computer analyzed) for several applications including (1) evaluation of wind erosion effects in cotton; (2) identifying the effects of rice borer infestation in sugarcane; (3) identifying sooty mold on citrus trees; and (4) differentation between shrubs, herbaceous vegetation, and soil in rangelands. Data acquired from this system also have been used to evaluate the efficiency of vegetation subtraction transformations in evaluating partially vegetated soils in southern Alabama (Mausel *et al.*, 1992).

Mid-Infrared (MIR) Video System

Most video systems have the ability to collect data from 0.4 to 1.1 μm. However, a MIR video system was developed jointly by the UDSA-ARS and the University of Florida. Two video cameras have been used with this system; one with a 0.9 to 2.2 μm capability (Everitt *et al.*, 1986) and the other with a 0.4 to 2.2 μm capability (Everitt *et al.*, 1987a). The cameras were used with a filter combination that transmitted spectral light within the 1.45 to 2.00 μm water absorption spectral region. Applications using MIR video have been somewhat limited by its low resolution and atmospheric interference. Research using these MIR cameras has included (1) distinguishing among plant species (Everitt *et al.*, 1986); (2) determination of succulent and nonsucculent plant species (Everitt *et al.*, 1987b); (3) identifying crop irrigation management potential (Escobar *et al.*, 1988); (4) differentiating between variable soil surface conditions (Everitt *et al.*, 1989a); and (5) detection of wild fires (Everitt *et al.*, 1989b).

University of Toronto Four-Camera System

A four-camera system was also developed at the University of Toronto (King, 1988; King and Vlcek, 1990). It was the first major research system to incorporate 13-mm format B&W solid-state cameras (0.4- to 1.1-μm sensitivity) with 0.01-μm band-pass filters. Both color composite video (from any three of four selectable bands using a custom built color encoder) and individual four-band B&W imagery can be acquired. An analog multiplexer (modified from a standard video switcher) is employed which switches between the four cameras at field or frame rates producing band sequential images that are recorded on a single Super VHS VCR. The color composite imagery is recorded on a second VHS VCR. Synchronization of the cameras is controlled through the encoder. A two-channel monitor is used to view the color and multiplexed B&W signals in flight. Data quality characteristics of this system (linearity, vignetting, noise, resolution, feature brightness variations with view angle, spectral data dimensionality, and distribution) have been evaluated thoroughly (King, 1988; 1991; 1992).

This system has been used in research on forest species discrimination and associated land cover classification (King, 1988; King and Vlcek, 1990). Spectral and textural analysis of data acquired from this system was used to assess sugar maple decline (King and Yuan, 1991; Yuan *et al.*, 1991). A sugar maple decline index was developed which was comparable to a ground-based index used by the Ontario Ministry of Environment. Evaluation of vegetation damage associated with acid leachate from mine sites, elevation modeling, and analysis of urban land-use classes are other research foci of videographers using data acquired from this system.

Utah State University High Resolution Multispectral Video System

Utah State University has developed a system similar to that used by USDA-ARS, Weslaco, Texas. Data are collected in three bands (10 nm wide centered on 0.55 μm, 0.65 μm, and 0.85 μm) using three high resolution commercially available video cameras with narrowband filters. The spectral imagery is collected on three professional grade S-VHS recorders. This system is supported by a global positioning system (GPS), two radiometers (one configured to Landsat MSS bands and the other configured to thermal IR), and a polycorder datalogger (Neale, 1992).

This system is used for agricultural and natural resources research. Recent applications include (1) riparian vegetation classification in watershed inventories; (2) quantification of fisheries habitat; (3) stream morphology changes; (4) aquatic habitat enhancement assessment; and (5) coastal wetlands resource inventories (Hardy and Neale, 1991).

Imagery Examples

Plate 1 illustrates the types of imagery commonly used in the course of basic and applied videography while Plate 2 (discussed in the future systems section) provides insight into digital camera imagery. Collectively, these plates provide a cross section of imagery used in videography along with selected CIR aerial photography taken concurrently.

Plate 1 shows comparisons of CIR video composite images and CIR photographs of two agricultural scenes. The video and photographic images of a cotton (*Gossypium histrsutum* L.) field infested with harvester ants (*Pogonamyrex barbatus* F. Smith) are shown in Plates 1A and 1B, respectively. Although the video image does not have as sharp a resolution as the photographic image, most of the ant mounds (white spots) can be easily detected in the video image. Plates 1C and 1D show video and photographic images of a cotton field with saline soils. The barren to sparsely vegetated saline areas can generally be distinguished as well in the video as in the photographic image. The color responses of the video composite images were comparable to the CIR photographic images in both scenes.

FUTURE DEVELOPMENTS AND APPLICATIONS IN VIDEOGRAPHY

Technical Problems

The reasons why video has not achieved as high a resolution as some other sensors are often more economic than technical. Videographers usually adapt high quality off-the-shelf equip-

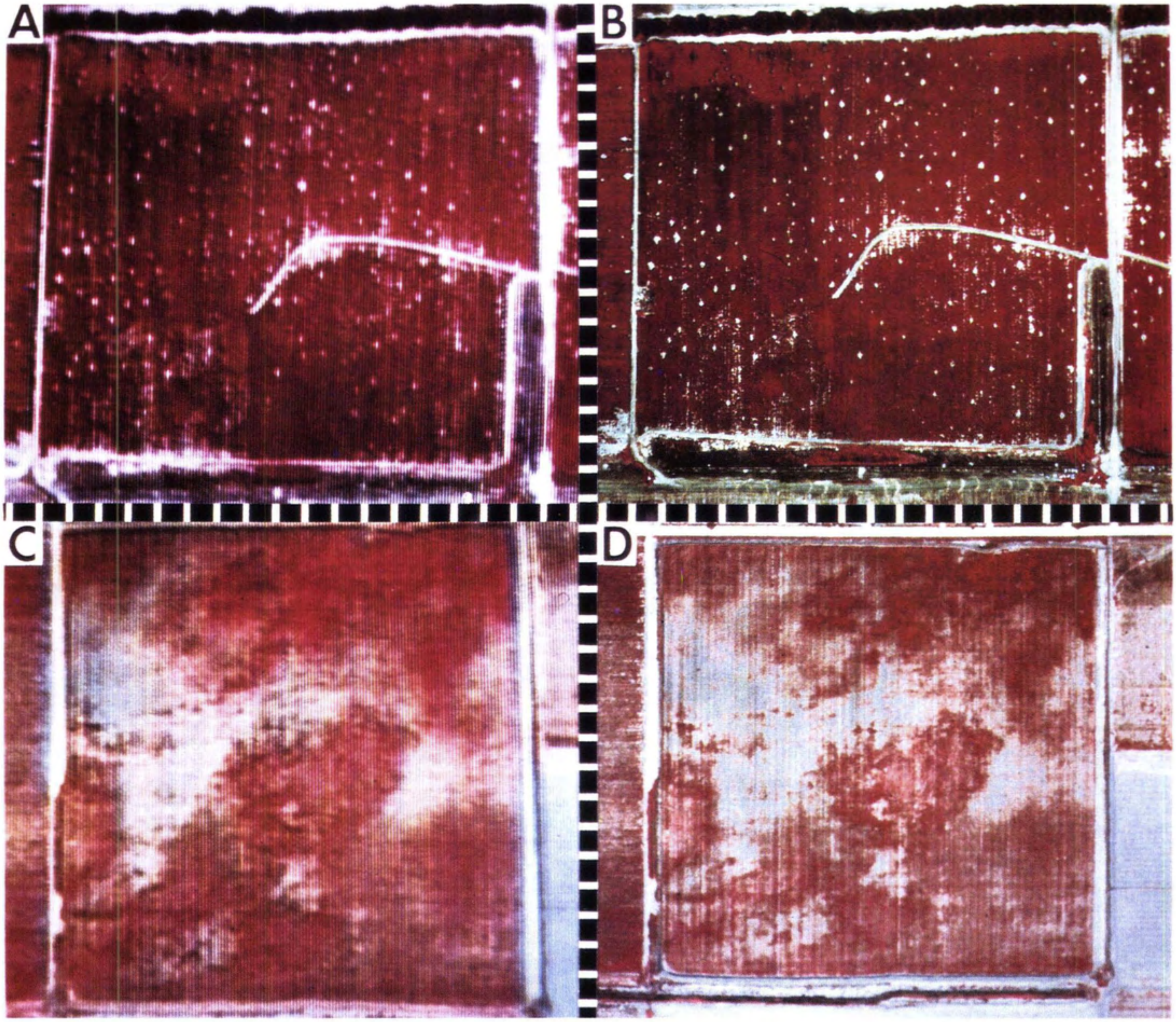


PLATE 1. Color-infrared video composite images (A and C) and color-infrared photographs (B and D) of a cotton field infested with harvester ants and a cotton field with saline soils, respectively. Imagery was obtained at an altitude of 900 m. The CIR photographs (derived from 70-mm film) are 1.5 × enlargements of original 1:6000 scale photos.

ment to use in scientific applications. This hardware serves the commercial and individual non-science user well and the regulations governing standards for use are focused on this large user group. However, this has caused the major electronics companies basically to ignore most scientific video needs because serving small market demand is not profitable. Thus, advances in video hardware, such as the S-VHS recorder, are major market-driven. The sophistication of video being demanded by all types of users is increasing, and it is likely that advances in video recorder and video display technology will continue, resulting in the improvement of current systems to the point where they may eventually approach the quality of some film products. Current video cameras available already have relatively high resolution, but the other components of a video system, such as recorders and display units, have much lower resolution.

Commercial video is becoming much more sophisticated and is the focus of research and development by large companies. Consequently, it is likely that the current resolution limitations are temporary. However, with improving quality of video components, it is probable that those applications requiring better resolution will become possible, albeit more costly, using advanced video systems. Thus, well-funded research labs may have access to these advanced systems in the near future, but the cost of them are likely to restrict their widespread use in research and applications during this decade.

CALIBRATION PROBLEMS

Videography has been avoided for some applications because of real or perceived calibration problems. Airborne videography commonly has been analyzed to compare relative spectral differences between features without attention to the absolute radiance or reflectance differences being imaged. Recently, more attention has been given to calibration, which should lead to more quantitative analysis in videography and greater acceptance of this form of remote sensing for certain applications. For example, Richardson *et al.* (1992) conducted a study in which airborne video digital count data were calibrated to refectance using ground reflectance standards. They showed that uncalilbrated video digital counts from imagery obtained with cameras with the automatic gain control on permitted quantitative relations among plant treatment differences, soil reflectance, and reflectance standards that were similar to those obtained with calibrated video. The literature is growing in addressing calibration and associated technical questions in videography (Palmer *et al.*, 1987; King, 1988, 1991, 1992; Ehlers *et al.*, 1989; Edwards and Schumacher, 1989; Gerbermann *et al.*, 1989; Richardson *et al.*, 1992). Crowther and Neale (1991) have suggested a promising video calibration method using a radiometer aimed at the center field-of-view of the video image. Thus, active research is being conducted in videography radiometric calibration, and results from this research should lead to encouraging additional video-based applications.

Geometric calibration or registration is also a concern of videographers. It has become increasingly important to integrate video-based data with other data sources (often in a geographic information system context) for final analysis or application. Videographers in general have not conducted much research on this topic, but scientists in other fields have; thus, methods are available to address this problem (El-Hakim, 1986; Curry *et al.*, 1986).

Future Systems

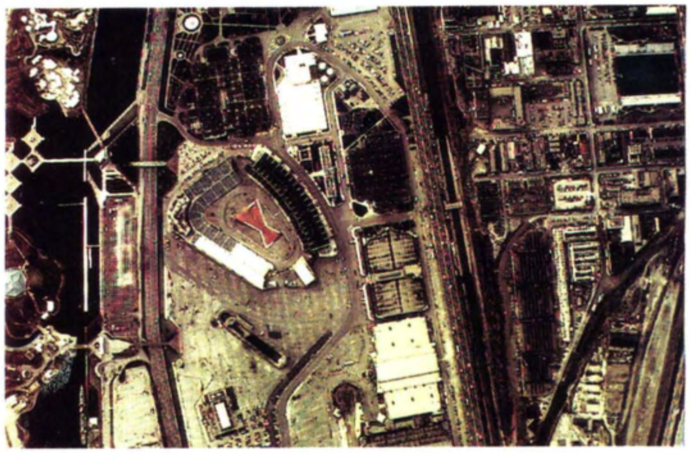
Even though improvements to current video systems are being made each year, there is an emerging technology supported by major corporations which promises to revolutionize videography research and applications. This new technology, which is now available in B&W or color form, is the digital frame camera.

King *et al.* (1992) evaluated the capabilities of a B&W VIDEK MEGAPLUS 1280 by 1024 digital frame camera. It was used to determine elevations in an urban area by flying the camera at 1525 m (0.7-m pixels) with 60 percent frame overlap. The digital images were read directly to an onboard computer. Preliminary analytical photogrammetric analysis of stereo pair imagery produced 1 m elevation accuracy in the 2.6 sq km area.

Kodak has a digital camera (1280 by 1024 CCD sensor) with 800-line color resolution and even higher resolution for the monochrome camera. These higher resolution cameras require slow platform speed to be most effective. Plate 2A shows an example of airborne color digital camera imagery of the Toronto, Ontario shoreline acquired on 28 November 1991. Plates 2B and 2C are color VHS video and 70-mm color photography of the same area. These three camera systems were flown simultaneously in order to compare the relative detail and content and assess the capabilities of the Kodak digital camera. It is evident that the digital camera imagery provides greater detail than the VHS video and it is much closer in quality to the 70-mm photo than is the VHS video image. The digital format and their separate RGB outputs are well-suited to computer analysis and photogrammetric applications.

Digital frame imaging cameras do not use a standard video signal; however, along with high definition television, they must be considered the future of the high-quality low-cost airborne remote sensing (sensors up to 4k by 4k have been developed). They are currently expensive and do not have the multispectral versatility of the video systems that are presently in use, although development of a multispectral version of this digital system will be completed during 1992 at Carleton University. During the 1990s, modification of the available digital frame cameras integrated with ancillary hardware will result in versatile and flexible systems comparable to those currently used, but with resolution approaching that of some film.

It is feasible and perhaps even likely that modified state-of-the-art videography systems used in airborne remote sensing during the early 1990s will be used experimentally at low Earth orbit elevations before the end of this century. Their initial role probably will focus on evaluation of rapid turn around moni-



(A)

(B)

(C)

Plate 2. Color digital camera image, color VHS video image, and 70-mm color photograph (A, B, and C, respectively) of the Toronto, Ontario shoreline on 28 November 1991.

toring of selected crops, but other types of Earth resources multitemporal analyses in near real time also will be explored.

CONCLUSIONS

Airborne videography is a relatively new branch of remote sensing that has an extensive list of research and applications. Low resolution data and, to a lesser degree, calibration problems have limited its use for selected applications; however, videography has grown significantly because of advantages not shared by many other sensors. Video technology is rapidly improving and eventually will have better resolution, but with the advantages of true narrowband multispectral data in digital form which are easily processed by computer.

The expansion of research and applications is likely to be large in the near future as digital frame cameras and high resolution video cameras will be configurated in ways comparable to existing multispectral systems. By the end of the decade, videographic systems will approximate the image quality of some types of film, and will have advantages due to their compatibility with image processing systems that should expand the basic and applied research horizons of this remote sensing specialization. Up to now, the focus in videography has been on basic research with some significant applications. It is likely that the combination of videography's substantial basic research base and improving technology will result in an increased emphasis on applied aspects of this speciality, while concurrently continuing to retaining a major interest in basic research.

ACKNOWLEDGMENTS

The authors thank Eastman Kodak Corporation for their loan of the digital camera system described in this paper and for their assistance in providing the imagery used in Plate 2. Thanks are also given to the Ontario Ministry of Natural Resources, Ontario Centre for Remote Sensing for their aid in video, a digital camera, and photography data acquisition (Plate 2).

REFERENCES

Airola, T. M., 1989. Monitoring the impact of arsenic contamination on forest vegetation in New Jersey, *Proc. 12th Biennial Workshop on Color Aerial Photography and Videography in the Plant Sciences*, Am. Soc. Photogrammetry and Remote Sensing, Falls Church, Virginia, pp. 94–98.

Ammon, D. S., D. F. Post, A. R. Huete, T. C. Tucker, and D. H. Kliman, 1987. Evaluation of multispectral video imaging as an agricultural research management tool, *Proc. 11th Biennial Workshop on Color Aerial Photography and Videography in the Plant Sciences*, Am. Soc. Photogrammetry and Remote Sensing, Falls Church, Virginia, pp. 244–251.

Bagheri, S., and M. Stein, 1992. Compatibility of MSC-02 and TM data for hydrological feature extraction, *Proc. 13th Biennial Workshop on Color Aerial Photography and Videography in the Plant Sciences*, Am. Soc. Photogrammetry and Remote Sensing, Falls Church, Virginia, in press.

Beck, L. A., A. R. Huete, C. Hutchinson, D. H. Kliman, and J. Walsh, 1988. Measuring semi-arid rangeland condition using multispectral video, *Proc. First Workshop on Videography*, Am. Soc. Photogrammetry and Remote Sensing, Falls Church, Virginia, pp. 42–49, 264.

Crowther, B. G. and C. U. Neale, 1991. Calibration of multispectral video imagery, *Proc. ASAE Symposium on Automated Agriculture for the 21st Century*, ASAE, Chicago, Illinois.

Curry, S., S. Baumrind, and J. Anderson, 1986. Calibration of an array camera, *Photogrammetric Engineering & and Remote Sensing* 52(5):627–63.

Edwards, G. J., 1982. Near-infrared aerial video evaluation for freeze damage, *Proc. Fla. State Hortical. Soc.* 95:1–3.

Edwards, G. J., and P. M. Schumacher, 1989. Evaluating the spectral response of your video camera, *Proc. 12th Biennial Workshop on Color Aerial Photography and Videography in the Plant Sciences*, Am. Soc. Photogrammetry and Remote Sensing, Falls Church, Virginia, pp. 212–215.

Ehlers, M., R. J. Hintz, and R. H. Green, 1989. High resolution airborne video system for mapping and GIS applications, *Proc. 12th Biennial Workshop on Color Aerial Photography and Videography in the Plant Sciences*, Am. Soc. Photogrammertry and Remote Sensing, Falls Church, Virginia, pp. 171–177.

El-Hakim, S., 1986. Real time image metrology with CCD cameras, *Photogrammetric Engineering & Remote Sensing* 52(11):1757–1766.

Escobar, D. E., R. L. Bowen, H. W. Gausman, and G. R. Cooper, 1983. Use of a near-infrared video recording system for the detection of freeze-damaged citrus leaves, *J. Rio Grande Valley Hortical. Soc.*, 36:61–66.

Escobar, D. E., J. H. Everitt, and M. R. Davis, 1988. Potential of mid-infrared video imagery for use in irrigation management studies, *Proc. First Workshop on Videography*, Am. Soc. Photogrammetry and Remote Sensing, Falls Church, Virginia, pp. 248–255.

Everitt, J. H., and P. R. Nixon, 1985. Video imagery: a new remote sensing tool for range management, *J. Range Manage.* 38:421–424.

Everitt, J. H., D. E. Escobar, C. H. Blazquez, M. A. Hussey, and P. R. Nixon, 1986. Evaluation of the mid-infrared (1.45 to 2.0 μm) with a black-and-white infrared video camera, *Photogrammetric Engineering & Remote Sensing* 52:1655–1660.

Everitt, J. H., D. E. Escobar, M. A. Alaniz, and M. R. Davis, 1987a. Using airborne middle-infrared (1.45 to 2.0 μm) video imagery for distinguishing plant species and soil conditions, *Remote Sens. Environ.* 22:423–428.

Everitt, J. H., D. E. Escobar, and P. R. Nixon, 1987b. Near-real-time video systems for rangeland assessment, *Remote Sens. Environ.* 23:291–311.

Everitt, J. H., D. E. Escobar, A. H. Gerbermann, and M. A. Alaniz, 1988a. Detecting saline soils with video imagery, *Photogrammetric Engineering & Remote Sensing* 54:1283–1287.

Everitt, J. H., D. E. Escobar, and R. Villarreal, 1988b. Evaluation of single-band-video and video-band-based indices for grassland phytomass assessment, *Photogrammetric Engineering & Remote Sensing* 54:1177–1180.

Everitt, J. H., D. E. Escobar, M. A. Alaniz, and M. R. Davis, 1989a. Using multispectral video imagery for detecting soil surface conditions, *Photogrammetric Engineering & Remote Sensing* 55:467–471.

Everitt, J. H., D. E. Escobar, and M. R. Davis, 1989b. Mid-infrared video: a possible tool for thermal analysis of wildfires, *Geocarto Int.* 4:39–45.

Everitt, J. H., K. Lulla, D. E. Escobar, and A. J. Richardson, 1990a. Aerospace video imaging systems for rangeland management, *Photogrammetric Engineering & Remote Sensing* 56:343–349.

Everitt, J. H., A. J. Richardson, D. E. Escobar, R. Villarreal, and D. L. Drawe, 1990b. Mapping native plant communities with color-infrared video imagery, *J. Imaging Technol.* 16:96–100.

Everitt, J. H., D. E. Escobar, R. Villarreal, J. R. Noriega, and M. R. Davis, 1991a. Airborne video systems for agricultural assessment, *Remote Sensing Environ.* 35:231–242.

Everitt, J. H., D. E. Escobar, and J. R. Noriega, 1991b. A high resolution multispectral video system, *Geocarto Int.*, In press.

Gausman, H. W., D. E. Escobar, and R. L. Bowen, 1983. A video system to demonstrate interactions of near-infrared radiation with plant leaves, *Remote Sens. Environ.* 13:363–366.

Gerbermann, A. H., D. E. Escobar, R. R. Rodriquez, and J. H. Everitt, 1988. Color and multispectral video imagery for detecting soil mapping units, *Proc. First Workshop on Videography*, Am. Soc. Photogrammetry and Remote Sensing, Falls Church, Virginia, pp. 37–41, 263.

Gerbermann, A. H., D. E. Escobar, and C. L. Wiegand, 1989. Comparison of aerial video, ground video and ground spectrometer data of field soils by wavelength and mapping unit, *Proc. 12th Biennial Workshop on Color Aerial Photography and Videography in the Plant Sciences*, Am. Soc. Photogrammetry and Remote Sensing, Falls Church, Virginia, pp. 178–186.

Hardy, T., and C. N. V. Neale, 1991. *Videography Prospect Report Sum-*

maries, Utah State University, Dept. of Agricultural and Irrigation Engineering, Logan, Utah, 1 p.

Hart, W. G., J. H. Everitt, D. E. Escobar, M. R. Davis, and M. G. Garza, 1988. Comparing imaging systems for assessment of diverse conditions of agricultural resources, *Proc. First Workshop on Videography*, Am. Soc. Photogrammetry and Remote Sensing, Falls Church, Virginia, pp. 160–165, 269–270.

King, D. J., 1988. *Development of a Multispectral Aerial Video System and its Application in forest and land cover type analysis*, Ph.D. dissertation, Faculty of Forestry, University of Toronto, Toronto, Canada. 296 p.

———, 1991. Determination and reduction of cover type brightness variations with view angle in airborne multispectral video imagery, *Photogrammetric Engineering & Remote Sensing* 57:1571–1578.

———, 1992. Evaluation of radiometric quality, spatial resolution and statistical characteristics of multispectral videography, *J. Imaging Science and Tech.*, in press.

King, D. J., and J. Vlcek, 1990. Development of a multispectral video system and its application in forestry, *Can. J. Rem. Sens.* 16(1):15–22.

King, D., and X. Yuan, 1991. Development of an airborne image-based maple decline index, *Proc. Ont. Min. Env. Tech. Conf.*, 25-26 Nov., Toronto, Ontario, Canada, pp. 337–340.

King, D., P. Walsh, and F. Ciuffreda, 1992. Elevation determination using airborne digital frame camera imagery, *Proc. 13th Biennial Workshop on Color Aerial Photography and Videography in the Plant Sciences*, Am. Soc. Photogrammetry and Remote Sensing, Falls Church, Virginia, in press.

Lulla, K., P. Mausel, D. Skelton, and W. Kramber, 1987. An evaluation of video-band based vegetation indices, *Proc. 11th Biennial Workshop on Color Aerial Photography and Videography in the Plant Sciences*, Am. Soc. Photogrammetry and Remote Sensing, Falls Church, Virginia, pp. 270-279.

Lusch, D. P. 1988. Super-VHS for improved airborne CIR videography, *Proc. First Workshop on Videography*, Am. Soc. Photogrammetry and Remote Sensing, Falls Church, Virginia, pp. 23–29.

Lusch, D. P., and F. J. Sapio, 1987. Mapping gypsy moth defoliation in Michigan using airborne video, *Proc. 11th Biennial Workshop Color Aerial Photography and Videography in the Plant Sciences*, Am. Soc. Photogrammetry and Remote Sensing, Falls Church, Virginia, pp. 261–269.

Mackey, H. E., J. R. Jensen, M. E. Hodgson, and K. W. O'Cuillin, 1987. Color infrared video mapping of upland and wetland plant communities, *Proc. 11th Biennial Workshop on Color Aerial Photography and Videography in the Plant Sciences*, Am. Soc. Photogrammetry and Remote Sensing, Falls Church, Virginia, pp. 252–260.

Maggio, R. C., D. M. Jacobs and R. D. Baker, 1989. Digital analysis of forest stands using scanned photography and still video images, *Proc. 12th Biennial Workshop on CIR Photography and Videography in the Plant Sciences*, Am. Soc. Photogrammetry and Remote Sensing, Falls Church, Virginia, pp. 130—135.

Manzer, F. E., and G. R. Cooper, 1982. Use of portable video-taping for aerial infrared detection of potato disease, *Plant Disease*, 66:665–667.

Mausel, P. W. (editor), 1988. *Proceedings First Workshop on Videography*, Am. Soc. Photogrammetry and Remote Sensing, Falls Church, Virginia, 270 p.

Mausel, P. W., G. Kalaluka, D. Mudderman, D. Escobar, and M. Davis, 1990. Multispectral video analysis of micro-relief dominated poorly drained soils in western Indiana, *Journal of Imaging Technology*, 16:113–119.

Mausel, P. W., M. Karaska, J. Lee, C. Mao, D. Escobar, and J. Everitt, 1991. Insights into water transparency through computer analysis of multispectral video data, *Int. J. Remote Sens.* 12:2485–2492.

Mausel, P. W., D. E. Escobar, J. H. Everitt, and R. S. Pearson, 1992. Assessment of selected soil parameter data in partially vegetated agricultural fields in southern Alabama, *Proc. 13th Biennial Workshop on Color Aerial Photography and Videography in the Plant Sciences*, Am. Soc. Photogrammetry and Remote Sensing, Falls Church, Virginia, 12 p., in press.

Meisner, D. E., and O. M. Lindstrom, 1985. Design and operation of a color infrared aerial video system, *Photogrammetric Engineering & Remote Sensing* 55:555-560.

Myhre, R. J., A. S. Munson, D. E. Meisner, and S. Dewhurst, 1987. Assessment of a color infrared aerial video system for forest insect detection and evaluation, *Proc. 11th Biennial Workshop on Color Aerial Photography and Videography in the Plant Sciences*, Am. Soc. Photogrammetry and Remote Sensing, Falls Church, Virginia, pp. 244–251.

Neale, C. M. V., 1992. An airborne multispectral video/radiometer remote sensing system for natural resource monitoring, *Proc. 13th Biennial Workshop on Color Aerial Photography and Videography in the Plant Sciences*, Am. Soc. Photogrammetry and Remote Sensing, Falls Church, Virginia, in press.

Nixon, P. R., D. E. Escobar, and R. M. Menges, 1985. Use of a multiband video system for quick assessment of vegetal condition and discrimination of plant species, Remote Sens. Environ. 17:203–208.

Nixon, P. R., D. E. Escobar, and R. L. Bowen, 1987. A multi-video false color imaging system for remote sensing applications, *Proc. 11th Biennial Workshop on Color Aerial Photography and Videography in the Plant Sciences*, Am. Soc. Photogrammetry and Remote Sensing, Falls Church, Virginia, pp. 295–305.

Palmer, R. A., R. C. Maggio, and P. T. Sprinz, 1987. Digital analysis of color infrared aerial video imagery, *Proc. 11th Biennial Workshop on Color Aerial Photography and Videography in the Plant Sciences*, Am. Soc. Photogrammetry and Remote Sensing, Falls Church, Virginia, pp. 280–285.

Repic, R. J., J. Lee, P. W. Mausel, D. Escobar, and J. Everitt, 1991. An analysis of selected water parameters in surface coal mines using multispectral videography, *Photogrammetric Engineering & Remote Sensing* 57:1585–1592.

Richardson, A. J., J. H. Everitt, and D. E. Escobar, 1992. Calibration of gain compensated aerial video remote sensing imagery using ground reflections standard, *Proc. 13th Biennial Workshop on Color Aerial Photograph Videography in the Plant Sciences*, Am. Soc. Photogrammetry and Remote Sensing, Falls Church, Virginia, in press.

Richardson, A. J., R. M. Menges, and P. R. Nixon, 1985. Distinguishing weed from crop plants using video remote sensing, *Photogrammetric Engineering & Remote Sensing* 52:1785–1790.

Stutte, G. W., R. Bours, and C. A. Stutte, 1990. ICAS quantification of nutrient stress in horticultural crops, *Proc. 12th Biennial Workshop on Color Aerial Photography and Videography in the Plant Sciences, Am. Soc. Photogrammetry and Remote Sensing*, Falls Church, Virginia, pp. 109–117.

Vlcek, J., 1983. Videography: some remote sensing applications, *Proc. 49th Annual Meeting Am. Soc. Photogrammetry*, pp. 63–69.

Vlcek, J., and D. King, 1985. Development and use of a 4-camera video system, *Proc. 19th Int. Symp. Remote Sensing of Environment*, pp. 483–489.

Wu, S. T., 1988. Utility of the C-band radar scatterometer and video system for determination of key tree canopy parameters, *Proc. First Workshop on Videography*, Am. Soc. Photogrammtry and Remote Sensing, Falls Church, Virginia., pp. 128–135.

Yuan, X. P., D. J. King, and J. Vlcek, 1991. Assessment of sugar maple decline based on spectral and textural analysis of multispectral aerial videography, *Rem. Sens. of Env.* 37(1):47–54.