Determination and Reduction of Cover Type Brightness Variations with View Angle in Airborne Multispectral Video Imagery

D. King
Department of Civil Engineering, School of Surveying, Ryerson Polytechnical Institute, 350 Victoria Street, Toronto, Ontario M5B 2K3, Canada

ABSTRACT: A simple and practical method for empirical determination of cover type brightness variations with view angle in multispectral airborne video imagery was developed. Video imagery acquired from several altitudes between late spring and early fall (i.e., with a multitude of illumination and view angle configurations) was analyzed. For several cover types, digitization of successive video frames was carried out with each cover type at five positions across a $\pm 16.7°$ view angle. Results of three-way factorial analysis with cover type, altitude, and spectral band as factors showed that each significantly affected the magnitude of cover type brightness variation with view angle. The variations were also consistently linear to near-linear, with cover type brightness increasing towards the side of the image opposite to the sun illumination direction. Evaluation of band ratios showed an average reduction in brightness variations to 42 percent of the raw data variations. In unsupervised clustering of the ratio data, single cover types which extended spatially across the total view angle were identified as single spectral classes instead of several as in the raw data. Post-classification merging of classes from the same cover type was therefore avoided.

INTRODUCTION

AIRBORNE MULTISPECTRAL VIDEO IMAGING

IN THE PAST DECADE, airborne videography has become a cost-effective tool in many remote sensing applications. It provides low cost imagery in electronic format suitable for digitization using a frame grabber. Images can be viewed in-flight for real time monitoring of target coverage. The high data generation rate (1/30s per image) provides continuous viewing of the land surface as it passes across the sensor view angle. Current analog video systems suffer from low spatial resolution in comparison to photography and sophisticated scanners. However, the fields of solid-state video and digital scanning are merging with the evolution of high resolution digital frame cameras.

Several analog multispectral video systems have been developed by research institutions and the private sector. They consist of either (i) multiple video cameras, each with an attached bandpass filter (e.g., Vlcek and King, 1985; Nixon *et al.*, 1985; Roberts and Evans, 1986; Hazard, 1987); (ii) a single camera with internal beamsplitting optics (e.g., Meisner and Lindstrom, 1985); or (iii) a single camera with external spinning filter wheel (e.g., Niedraurer and Paul, 1985). The former configuration requires multiple video recorders and synchronization circuitry (Nixon *et al.*, 1985) or a single recorder and electronic signal manipulation to record all cameras on one VCR (Vlcek and King, 1985). The second configuration produces color infrared composite imagery and separate band outputs corresponding to the RGB signals. The third configuration produces band sequential video images which are recorded onto a single VCR.

Each of these system types has been extensively applied both in research and operational projects. Applications have been primarily concerned with extraction of multispectral image information for vegetation identification/classification or vegetation health/damage assessment. Examples include evaluation of rangeland conditions (Everitt and Nixon, 1985), discrimination of forest and land-cover types (King and Vlcek, 1990; King *et al.*, 1986), mapping of gypsy moth defoliation (Lusch and Sapio, 1987), and monitoring of sugar maple decline (Yuan *et al.*, 1989). These represent a limited sample of the many applications of videography which have been reported in journals or symposium proceedings (e.g. – the ASPRS Special Workshop on Videography in 1988 and the ASPRS Biennial Color IR Photography and Videography Conferences in 1985, 1987, and 1989).

RESEARCH BACKGROUND

In these and other applications which require two-dimensional quantitative image processing and analysis, video imagery suffers from the combined effects of image plane irradiance variations with view angle due to optical characteristics ($\cos^4$ brightness reductions with view angle and vignetting), atmospheric attenuation, and bi-directional feature reflectance variations (see Slater, 1980). In this study, the primary research objective was digital land-cover classification using multispectral airborne video (see King and Vlcek (1990) and King (1988)). Consequently, analysis of these factors individually and data calibration were not performed because they were not as important as empirical analysis of the *net* cover type image brightness variations and their effects on multispectral classification. The goals of this research were to (i) produce a simple and easy to implement methodology for determination of *net* cover type brightness variations with view angle in digital multispectral video images, (ii) determine the magnitude and trend of these cover-type brightness variations, (iii) analyze the effectiveness of band ratioing in reducing these variations, and (iv) evaluate multispectral classifications for improvements due to band ratioing.

VIDEOGRAPHY ACQUISITION

MULTISPECTRAL VIDEO SYSTEM

The four-camera video sensor (4CVS) developed by Vlcek and King (1985) was used for data acquisition. A schematic of the system is shown in Figure 1. It includes (i) four solid-state (CCD) black-and-white video cameras (sensitive in the 400nm to 1100nm spectral range) with narrowband interference filters mounted on the front of the lenses, (ii) a band-sequential multiplexer which switches between the cameras at field (1/60s) or frame (1/30s) rates, (iii) a color encoder which provides color or false color composite imagery from combinations of three user selectable cameras (spectral bands), (iv) two VCRs for separate recording of the sequential black-and-white and color/false color

PHOTOGRAMMETRIC ENGINEERING & REMOTE SENSING,
Vol. 57, No. 12, December 1991, pp. 1571–1577.

0099-1112/91/5712–1571$03.00/0

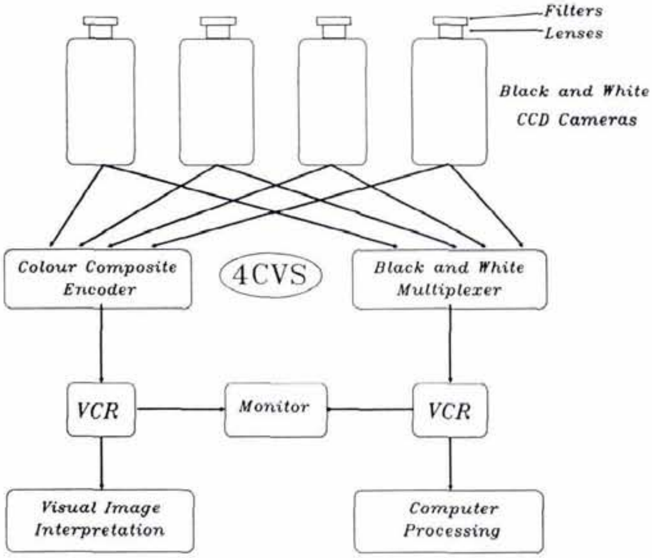

FIG. 1. Schematic of the 4CVS.

imagery, and (v) a monitor for in-flight monitoring of both video signals. The system is described in more detail in King (1988) and King and Vlcek (1990).

AERIAL IMAGERY ACQUISITION

From 1985 to 1987, multispectral aerial video imagery was acquired several times using the 4CVS for the primary purpose of evaluating its potential in land-cover classification. Table 1 lists the dates, local sun times (LST), sun elevations and azimuths, altitudes, and flight directions for flights over the test sites described below. It illustrates the variety of data acquisition conditions from which the analysis was conducted. All imagery was acquired with 8-mm focal length lenses which resulted in an angle of view of ±16.7° in the vertical image dimension. Additional flight details are given in King (1988).

TEST SITES

Two test areas in southern Ontario and one test area in northern Ontario were imaged. Site 1 in southern Ontario was just northwest of Toronto and included two conservation areas plus adjacent agricultural land. The cover types sampled at this site were uniform hay crop, short grass, mixed deciduous forest (primarily maple: *Acer spp.*, beech: *Fagus grandifolia*, and ash: *Fraxinus spp.*), single deciduous trees, bare soil, red pine (*Pinus resinosa*) plantations, and water. Site 2 in southern Ontario was about 100 km east of Toronto near the town of Orono. It included agricultural land and a forest nursery. The cover types sampled were the same as at Site 1 with the exception of water and the addition of Norway spruce (*Picea abies*) plantations, Scots pine (*Pinus sylvestrus*) plantations, and sod. In northern Ontario, Site 3 consisted of part of a large boreal forest management region near the town of Kapuskasing. Cover types which were analyzed from this data were black spruce (*Picea mariana*), deciduous trees occurring as minor groups within the black spruce forest (aspen (*Populus tremuloides*), balsam poplar (*Populus balsamifera*), and white birch (*Betula papyrifera*)), wild grass, bare soil, and water.

IMAGE ANALYSIS METHODOLOGY

Videography is unique in that its format is a two-dimensional frame exposure of the land surface which, for conventional NTSC video, is repeated every 1/30s. Consequently, in aerial imaging, successive video frames have very large overlap. An object can be viewed from a continuously varying sun angle/view angle combination as it crosses the vertical image dimension from top to bottom (i.e., it may be present in several hundred video frames as the aircraft passes over it). This is different from both photography and line scanning. In stereo aerial photography, an object may only be present in a few images using typical overlaps while, in line scanner images, the object is imaged only in the swath directly beneath the aircraft.

IMAGE DIGITIZATION AND PRE-PROCESSING

Four-band video imagery which was recorded from the switcher output was digitized using a 1024 by 1024 frame grabber partitioned into four 512 by 512 quadrants. The frame grabber was programmed to store four consecutive video frames, one in each quadrant. Because the switcher output consisted of four-band sequential video frames, a set of four spectral bands could be digitized at once. Four-band image data sets were digitized with each selected cover type at five positions (view angles) across the vertical image dimension (±16.7°). The positions were near the top (approx. −14°), middle of upper half (approx. −7°), center (0°), middle of lower half (approx. +7°), and bottom (approx. +14°). At the time this research was conducted, the image analysis system which was available was only capable of processing 256 by 240 digital images. Consequently, each 512 by 512 image had to be re-sampled using a 2 by 2 averaging filter.

COVER TYPE SAMPLING AND STATISTICS EXTRACTION

Once five multispectral data sets were obtained for each cover type, a window was delineated within them for extraction of multiband statistics. The window was consistently located to ensure that the same spatial area within each cover type was sampled at each view angle. The windows were between 100 and 1200 pixels depending on cover type area and uniformity. Figure 2 shows a schematic of this sampling procedure in a forest stand. A window has been delineated in the same location within the stand at five view angles (i.e., in five digitized images) as the stand passed from top to bottom of the field of view.

The mean cover type brightness was determined at each position and linearly correlated with view angle (visual analysis of the data showed that this was the best trend). As well, the maximum per cent difference in mean cover type brightness from nadir (MPDN) (see Kimes (1985)) in the vertical image dimension was determined (the term nadir is applied to the image center at 0° angle of view). Due to difficulty in sampling at the very edges of the image, the top and bottom samples were

TABLE 1. VIDEOGRAPHY ACQUISITION INFORMATION.

Site	Date/Time (LST)	Sun Elevation/Azlmuth	Altitude (m)	Flight Direction
1	04 June 85, 7:45–9:15	34–50/90–108	304,610,1220	E-W, W-E
	28 Sept 85, 7:45–8:45	18–29/110–122	610,1220	E-W, W-E
	27 Sept 87, 10:00–10:30	39–42/144–151	1220	E-W
2	04 June 86, 12:45–13:45	69–62/209–238	460,915	E-W, W-E
3	08 July 86, 12:45–14:15	65–54/204–239	304,610,1220	N-S, S-N

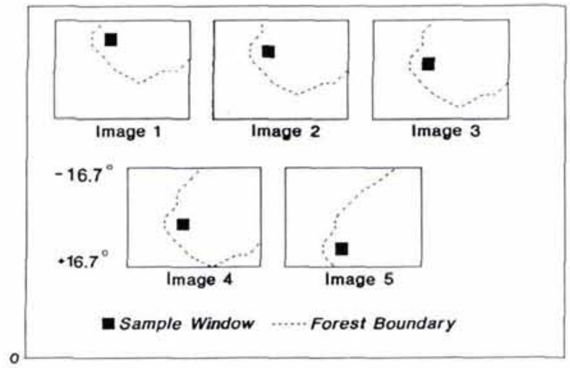

FIG. 2. Schematic showing typical sampling procedure for a forest stand at five view angles. Flight direction is towards the top of each image (−16.7°).

typically located at about ±13.8°. This sampling and analysis procedure was repeated for all cover types in three spectral bands which were common to each of the flights. The bands were 530 to 570nm (green), 630 to 670nm (red), and 780 to 820nm (near IR). Including repetitions within cover types (where the cover type extended over a large enough area to be sampled in more than one location), the total number of linear correlations and MPDN analyses conducted was 174.

At Site 2, it was possible to sample seven cover types (listed in Table 2) in imagery taken from two altitudes to determine if variations in altitude, cover type, or spectral band had significant effects on brightness variations from nadir. The method used was a factorial analysis of variance.

BAND RATIO ANALYSIS

Band ratioing is a common image processing technique which can be used to reduce unwanted data variation with view angle. Variations caused by atmospheric attenuation, topography, and illumination-viewing geometry are most effectively reduced when they are consistent from band to band. Results from this research (discussed later in *Results* section) illustrated this consistency, so several band ratios were tested as means to reduce them. Preliminary tests were conducted to compare (i) simple ratios (B_i/B_j), (ii) normalized difference ratios (B_i-B_j/B_i+B_j), and (iii) band-sum ratios ($B_i/\Sigma B_i$) (based on software capabilities). The best method was then applied to all cover types in all bands to evaluate the overall reduction in MPDN for all flight conditions.

LAND-COVER CLASSIFICATION

A portion of one of the conservation areas in Site 1 was used as a test site to compare classification of land-cover types using raw data and ratioed data. (This part of the research was part of a larger study to determine the optimum image processing procedures for classification of airborne video (see King and Vlcek (1990) and King (1988)). The data were acquired 4 June 1985 (see Table 1). The four original video bands of the site are shown in Plates 1a to 1d. Many shadows were present in the data due to the low sun elevation. Band 4 (880 to 920nm) was slightly out of focus due to incorrect CCD sensor positioning.

Unsupervised systematic sampling of the scene every 8th row and column produced 960 training pixels. These were input to a k-means clustering procedure (Frank and Luman, personal communication). (Note: unsupervised methods were used to avoid bias in training data selection; the k-means approach was used based on software availability.) Clusters were merged iteratively until all paired values of transformed divergence were greater than 1500. The resulting training data were then input to a maximum-likelihood classifier. The ground survey image shown in Plate 1e shows the areas of homogeneous cover types in this scene (listed in Table 3a) which were identified after extensive field survey and comparison with Metro Toronto Region Conservation Authority maps. This image was used as a comparison to the automated classifications for accuracy evaluation on a pixel-by-pixel basis.

RESULTS

Figure 3 shows typical examples of the variation of mean sample values with view angle in each band for soil, red pine, aspen, and grass. The sun azimuth is indicated by an arrow in

TABLE 2a. MPDN VALUES FOR SEVEN COVER TYPES IN IMAGERY FROM TWO ALTITUDES IN THREE SPECTRAL BANDS. COVER TYPES, ALTITUDES, AND BANDS AS SHOWN.

	Altitude					
	460 m			915 m		
	Band (nm)			Band (nm)		
Cover Type	550	650	800	550	650	800
Norway Spruce	17.4	22.0	10.9	13.0	13.9	10.6
Scots Pine	4.0	9.3	3.4	10.7	8.0	2.4
Sod	8.1	16.6	10.7	14.5	12.8	6.1
Grass	19.9	34.6	13.5	12.9	21.0	2.3
Deciduous forest 1	14.5	13.5	22.6	8.8	10.2	5.1
Deciduous forest 2	17.1	11.0	10.6	10.0	18.0	6.5
Deciduous forest 3	9.1	11.0	5.0	8.8	19.0	5.8

TABLE 2b. FACTORIAL ANALYSIS OF VARIANCE RESULTS FOR DATA IN TABLE 2a.

Sources of Variation	df	SS	MS	F
Cover types (C)	6	441.97	73.66	4.33*
Altitudes (A)	1	98.75	98.75	5.81*
Bands (B)	2	396.78	198.39	11.67**
C X A	6	233.01	38.84	2.28
C X B	12	256.39	21.37	1.26
A X B	2	29.38	14.69	0.86
C X A X B	12	204.08	17.00	–

*Significant at $\alpha = 0.05$, **Significant at $\alpha = 0.01$

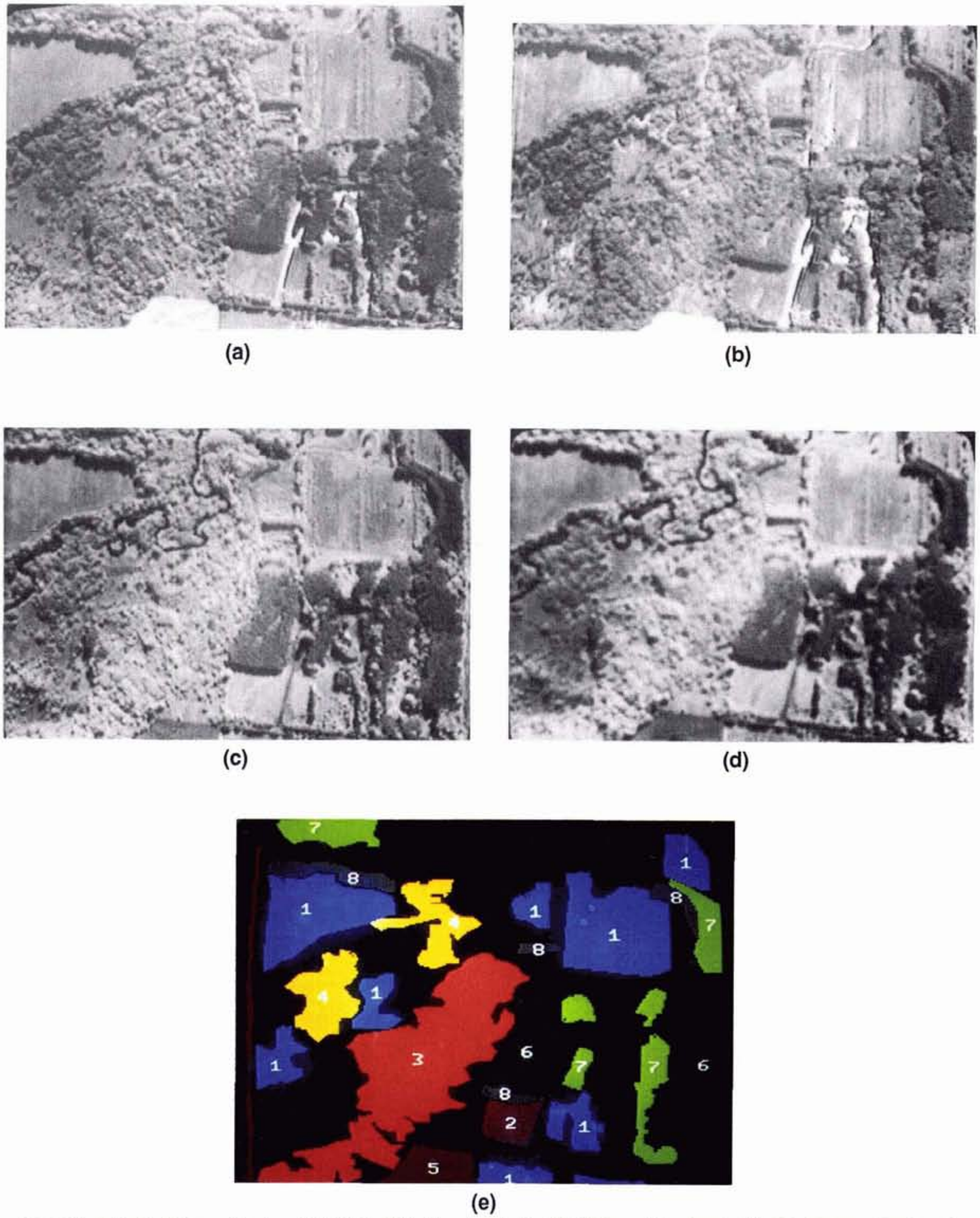

PLATE 1. (a) 530–570nm video band. (b) 630–670 video band. (c) 780–820nm video band. (d) 880–920nm video band. (e) Ground survey image. Cover types are listed in Table 3a.

plan view in relation to the four cardinal directions N,S,E,W. The direction of flight was towards the top of the image (the left side of each graph at $-15°$ angle of view). The sun azimuth and elevation for each cover type are not given because the exact time of imaging was not known. Refer to Table 1 for approximate imaging times and illumination angles. These curves are very typical of the results obtained for all cover types in all bands under the given imaging conditions. The standard deviation about each mean ranged from 1.7 percent of the mean value to 17.2 percent. In general, smooth features such as sod had low data variance while rough features such as forest canopies had high data variance.

Aggregated Results

The average maximum percent difference from nadir (MPDN) aggregated for all the data (i.e., all cover types, bands, altitudes) was 12.8 percent (s = 4.8 percent, n = 174). This means that, on average, the maximum variation in mean cover type brightness in the vertical view angle of ±13.8° was ±12.8 percent from the nadir brightness. The trend in brightness variation was near linear for all cover types (r^2 = 0.69 on average, s_r = 0.30) with an increase in cover type brightness towards the side of the image opposite to the sun illumination direction (see Figure 3).

Analysis of Effects of Cover Type, Spectral Band, and Altitude on Cover Type Brightness Variations in the Site 2 Data

Table 2a shows the MPDN values for seven cover types at Site 2. The data are for two altitudes and three spectral bands. Several points about each variable can be made that were typical of all the data acquired in southern and northern Ontario. First, in relation to cover types, differences in MPDN within a highly varied cover type (e.g., deciduous forest) were often as large as MPDN differences between unlike cover types. This is probably due to sun-sensor-target geometry differences between the samples within such a cover type. Consequently, these samples could not be aggregated but had to be considered as separate cover types (e.g., deciduous 1,2,3) in the analysis of variance. Also, three-dimensional cover types such as forest canopies or individual trees which generally show visible differences between highlighted and non-highlighted portions of the crowns did not show greater MPDN values than flat cover types such as soil, water, and grass as might have been expected. Second, in relation to altitude, there was usually a decrease in MPDN for each cover type in a given band as altitude increased from 460m to 915m. Third, in relation to spectral bands, the MPDN variation of data acquired in the 630 to 670nm band was significantly greater (α = 0.05) than the 530 to 570nm and 780 to 820nm bands. The 530 to 570nm band variations were greater than the 780 to 820nm band but not significantly.

The significance of the variables cover type, altitude, and band on MPDN values was tested in a three-way factorial analysis of variance of the Site 2 data. Cover type had seven levels, altitude had two, and band had three. The three-factor interaction was used as the error term to determine F values because no replications were possible with the given data (see Snedecor and Cochrane (1980)). The results are given in Table 2b. They show that each variable was significant at either α = 0.05 or 0.01. This indicates that the magnitude of cover-type variation with view angle is significantly affected by the altitude of image acquisition, the spectral band, and the cover type itself.

Reduction of Cover-Type Brightness Variations Using Band Ratios

The linear trends shown in Figure 3 were consistent in all spectral bands (i.e., the curves were nearly parallel) thereby indicating band ratioing as a potentially effective means for reduction of variations with view angle. Of the three ratio types

Table 3a. Site 1 Cover Types Used in Classificaiton.

1.	hay/open
2.	short grass
3.	mixed deciduous 1: – hard maple (Acer saccharum) – ash (Fraxinus spp.) – beech (Fagus grandifolia)
4.	mixed deciduous 2: – Manitoba maple (Acer negundo) – ironwood (Carpinus caroliniana) – black willow (Salix nigra)
5.	bare soil
6.	conifer 1: – red pine plantation (Pinus resinosa)
7.	conifer 2: – mostly white spruce (Picea glauca) – red pine (Pinus resinosa) – cedar (Thuja occidentalis) – white pine (Pinus strobus)
8.	shadow

Table 3b. Contingency Table for Classification of Raw Video Data.

	Ground Survey Cover Types								
	1	2	3	4	5	6,7	8	Σ	%ACC
C 1	4302	–	41	19	15	57	24	4458	96.5
L 2	483	55	20	7	64	2	2	633	8.7
A 3	851	586	5277	628	–	46	36	7424	71.1
S 4	1996	82	765	777	–	29	–	3695	21.0
S 5	18	1	26	1	1747	74	–	1826	95.6
'6,7	99	–	201	811	–	4717	148	5976	78.9
N 8	23	–	24	12	–	1092	817	1968	41.5
Σ	7772	724	6354	2255	1826	6017	1073	25980	
%ACC	55.4	7.6	83.1	34.1	95.7	78.4	76.1		68.1

Table 3c. Contingency Table for Classification of Video Data Processed by Band Ratioing.

	Ground Survey Cover Types								
	1	2	3	4	5	6,7	8	Σ	%ACC
C 1	5306	108	66	122	19	744	42	6407	82.8
L 2	950	410	616	689	–	80	11	2756	14.9
A 3	1203	181	5267	725	–	207	140	7723	68.2
S 4	111	–	168	544	4	148	29	992	54.8
S 5	23	24	27	–	1689	–	–	1763	95.8
'6,7	299	1	145	107	114	4608	760	6034	76.4
N 8	17	–	60	68	–	12	91	248	36.7
Σ	7909	724	6349	2255	1822	5799	1073	25923	
%ACC	67.1	56.6	83.0	24.1	92.7	79.5	8.5		69.1

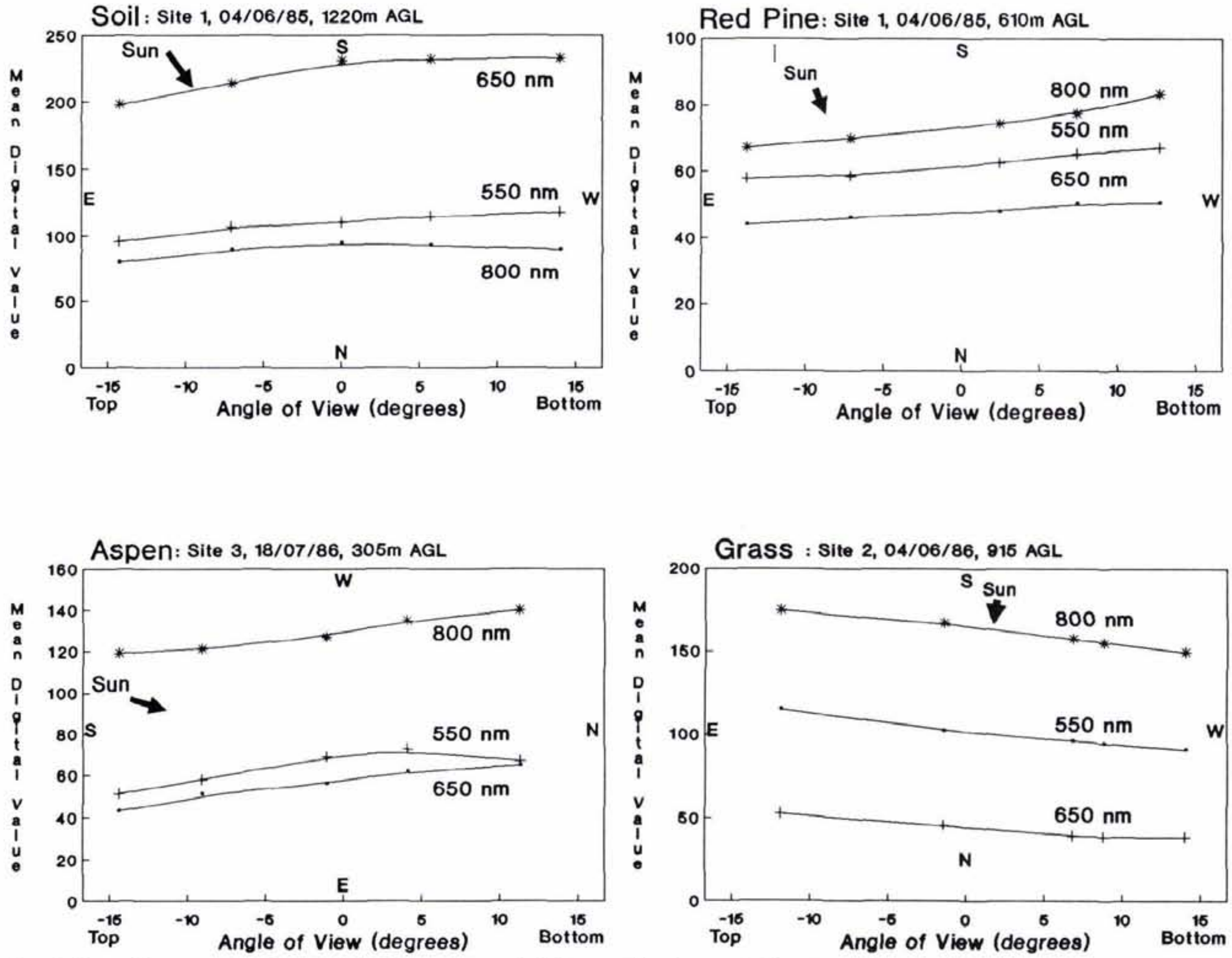

FIG. 3. Example curves showing variation in cover type brightness with view angle from top to bottom of image.

listed previously, the band-sum ratio technique provided reductions up to three times greater than the other two in separate tests. It was therefore applied to all the data. The resulting average MPDN for all cover types was reduced significantly to 5.2 percent (s = 2.7 percent) or 42 percent of the average for the original data. The residual variation in cover-type brightness in the band ratioed images can be attributed to deviations of the cover type brightness curves from parallelism. This could result from a number of factors, including (i) cover type sampling error (± 1 row or column sampling error for a cover type from band to band was probable in many cases), (ii) anisotropic reflectance variations from band to band with view angle (Kimes *et al.*, 1980), and (iii) natural and electronic data noise.

EFFECTS OF BAND RATIOING ON LAND-COVER CLASSIFICATION

The results of classification of the Site 1 cover types listed in Table 3a are given in Tables 3b (raw data) and 3c (ratioed data). Both classifications were smoothed using a 3 by 3 moving window majority filter before generation of these tables. (This filter was shown to have little effect on classification accuracy (King, 1988)). Cover types (1 and 2), (3 and 4), and (6, 7, and 8) were the most confused in both classifications. The confusion between red pine (class 6) and other conifers (class 7, which also included red pine) was so great that these cover types were merged into a single conifer cover-type class.

Band-sum ratioing improved the per pixel classification accuracy only slightly from 68.1 percent to 69.1 percent. However, in the band-sum ratio data, cover types which extended across the view angle were usually defined as single spectral clusters. In the raw data, the same cover types were associated with more than one distinct spectral cluster, and the resulting cover type classes had to be merged after classification. A good example of this was the large mixed deciduous 1 cover type (class 3) which extended diagonally across the image. In the ratio data, it was completely defined by one spectral cluster which resulted in a single class after classification. In the raw data, three distinct spectral clusters resulted due to the effects of brightness variations with view angle. The three classes produced by the classifier had to be merged after classification to properly define this area. The end result was that the per pixel accuracy for the raw data class created by merging was similar to that for the single class from the band ratio data. However, using the ratio data, the post-classification merging step was eliminated.

DISCUSSION

The data utilized for this study represent a wide range of illumination/viewing conditions which were advantageous in analyzing overall cover-type brightness variations in multispectral videography. Because all 174 correlations of image brightness with view angle showed linear trends, the method of band ratioing to reduce them performed well.

In land-cover classification, the reported accuracies are not high enough to be useful for mapping, but further improvements should be possible through improved data acquisition planning, data processing, and information extraction. For example: (1) in the data acquisition stage, narrow bandwidth spectral bands which optimize the separation of forest species and land-cover types is critical. For other advanced sensors (e.g., MEIS II), specific "forestry" filter sets are now used for this purpose (McColl, personal communication). Also, the test data used in this classification were constrained by aircraft availability and were thus hindered by early morning shadows, poor illumination angles, and spring vegetation conditions. Improved sun angle and vegetation development should improve cover type separability. (2) In the image processing stage, further improvements in classification accuracy can be achieved through addition of other processing techniques such as noise reduction, addition of texture information, etc. (see King and Vlcek (1990) and King (1988)). (3) In the classification stage, unsupervised selection of training data was used to avoid bias of supervised training in such large-scale imagery where cover types were easily identified. However, it has been shown that supervised training data selection significantly improved classification accuracy (King, 1988). (4) Finally, the area selected for classification was mostly forested with a high degree of within-cover type variance. Classification of more homogeneous cover types can greatly improve accuracy.

CONCLUSIONS

The method of digitizing several images of a given cover type, each with the cover type at a different position or view angle, has enabled the extraction of statistics and determination of the variation in image brightness of the cover type over the sensor view angle. The variations were found to be consistently near-linear for the imaging conditions tested. In terms of maximum percent difference of cover-type brightness from nadir to the image edge, all cover types showed significant variation, being in the order of 12.8 percent on average for view angles of $\pm 13.8°$. Cover-type variations did, however, differ significantly between features, spectral bands, and imaging altitudes. Such information is useful in flight planning and in understanding image characteristics.

Band-sum ratios were found to be effective in reduction of cover-type brightness variations. In unsupervised clustering, cover types which extended across the view angle were represented by single spectral clusters whereas in the raw data they were represented by more than one spectral cluster due to large brightness variations. The often tedious post-classification step of merging classes which represent the same cover type was eliminated because image brightness was more uniform across the view angle.

ACKNOWLEDGMENTS

This research was supported by the National Science and Engineering Research Council, the Canada Department of Energy, Mines and Resources, and Forestry Canada. Appreciation is extended to Dr. J. Vlcek, Faculty of Forestry, University of Toronto, for initial support.

REFERENCES

Everitt, J., and P. Nixon, 1985. False colour video imagery: a potential remote sensing tool for range management. *Photogrammetric Engineering & Remote Sensing* 51(6):675–679.

Hazard, B., 1987. Detection of the sear and yellow leaf in the Texas piney woods. *Proc. 11th Biennial Workshop on CIR Photography and Videography in the Plant Sciences and Related Fields*, Weslaco, Texas. p. 233–243.

Kimes, D., 1985. Modellisation of the optical scattering behavior of vegetation canopies. *Proc. 3rd Colloquium of the ESA*. Paris, France. pp. 157–163.

Kimes, D., K. Ransom, and J. Smith, 1980. Vegetation reflectance measurements as a function of solar zenith angle. *Photogrammetric Engineering & Remote Sensing* 46:1563–1573.

King, D., 1988. *Development of a Multispectral Aerial Video System and its Application in Forest and Land Cover Type Analysis*. Ph.D. Thesis, Faculty of Forestry, University of Toronto. Toronto Ontario M5S 1A1, Canada. 296p.

King, D., and J. Vlcek, 1990. Development of a multispectral airborne video system and its application in land cover classification. *Can. J. Remote Sensing* 16(1):15–22.

King, D., D. Jayasinghe, and J. Vlcek, 1986. Spectral and spatial analysis of multiband video images. *Proc. 52nd meeting ASPRS*, Washington, D.C., pp. 85–91.

Lusch, D., and F. Sapio, 1987. Mapping gypsy moth defoliation in Michigan using airborne CIR video. Proc. 11th Biennial Workshop on Color Aerial Photography and Videography in the Plant Sciences. Weslaco, TX. p. 261–269.

Meisner, D., and O. Lindstrom, 1985. Design and operation of a color infrared aerial video system. *Photogrammetric Engineering & Remote Sensing* 51(5):555–560.

Niedrauer, T., and C. Paul, 1985. A portable multispectral video system. *IEEE: Ocean Eng. Soc.* 1:304–307.

Nixon, P., D. Escobar, and R. Menges, 1985. Use of a multiband video system for quick assessment of vegetation condition and discrimination of plant species. Remote Sensing of Environment Vol. 17(2):203–208.

Roberts, A., and D. Evans, 1986. Multispectral video system for airborne remote sensing: sensitivity, calibrations, and corrections. *Proc. 10th Can. Symp. on Remote Sensing*. Edmonton, Alta. pp. 729–737.

Slater, P., 1980. *Remote Sensing: Optics and Optical Systems*. Addison-Wesley. Don Mills, Ont. 575p.

Snedecor, G., and W. Cochrane, 1980. *Statistical Methods*. 7th ed. Iowa State University Press. pp. 318–320.

Vlcek, J., and D. King, 1985. Development and use of a 4-camera video system in resource surveys. *Proc. 19th Int. Symp. on Remote Sensing of Env.*, Ann Arbor, Michigan. pp. 483–489.

Yuan, X., D. King, J. Vlcek, and D. McLaughlin, 1989. Application of aerial multispectral videography and colour/colour IR photography in sugar maple decline assessment. *Proc. 12th Can. Symp. on Remote Sensing*, Vancouver, B.C. pp. 2385–2389.

(Received 22 August 1990; revised and accepted 27 February 1991)