Report for Earth Observation Centre (EOC) Task 3.1: Hi-Resolution Scene Brightness and BRDF

Testing of Scene Brightness or BRDF correction techniques using DMSV data

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June 9, 2001.

An objective of the High Resolution Scene Brightness or BRDF Task for the CSIRO Earth Observation Centre is the development of guidelines for best practice outputs (including prototype software) for high resolution Aerial Photography, Video, Digital Camera and Airborne Scanner data to minimise the effects of scene brightness. A main outcome of the task has been the development of the Reference Method and software by CSIRO Exploration and Mining (CEM). Software was made available to the EOC at the July 2000 Science Meeting and the developers have asked for feedback from the EOC community.

Tasks and outcomes:

This report addresses Stage 1 'Testing and evaluation' of the extended BRDF task objectives 1-3.

1. Evaluate the CEM Reference method software for operational use and provide feedback to the CEM team.

2. Compare the results of DMSV data corrected using the (a) the CEM Reference Method (Ong *et al.*, (2000a)), and (b) the semi-empirical procedure developed by CSE (Pickup *et al.* (1995a), Pickup *et al.* (1995b)) referred to as the CSE method in this report.

3. Contribute to recommendations on situations where the CEM Reference Method might be an appropriate procedure for use with DMSV data.

Data and Methods

The CSE DMSV aerial video system consists of four CCD cameras fitted with 25nm wide filters centred on: blue- 450nm, green- 550nm, red- 650nm and nir-770nm. The CSE archive contains imagery acquired over a range of landscapes and flight conditions, as listed in Appendix table A1. We tested the CEM Reference Method using two scales – (1) correcting video data with a one metre pixel size using Landsat TM (30m) as the reference image and (2) correcting video data with a 20cm pixel size using video data with a 1.8 metre pixel size as the reference image.

The following transects were used:

- Open woodland transects acquired under different conditions (OW1H and GTSSH transects)
- A transect containing areas of Mulga (*Acacia aneura*) and shadow as well as bare soil providing strong contrast (KHMM transect)
- A mixed transect (H2A and H20A transects)

All transects were in the Kunoth Paddock test site (23^{o} 32' S, 133^{o} 34' E) and flight details are given in Table 1. Corrections were applied for the effects of aircraft motion, camera misalignment and lens distortion (Pickup *et al*. 1995a, Pickup *et al*. 1995b). Details of the Landsat TM data used in the CEM Referencing Method correction are given in Table 2.

Table 1. Details of DMSV aerial video data used.

Transect name	**OW1H**	**GTSH**	**KHMM**
	open woodland	open woodland	Mulga (*Acacia aneura*) & bare soil
Date acquired	3/11/98	26/9/95	26/3/97
Flying height AGL	1420 m	1420 m	1420 m
Pixel resolution	1 m	1 m	1 m
Transect bearing	127^{o} magnetic	124^{o} magnetic	68^{o} magnetic
Solar zenith	19.8 degrees	47.8 degrees	38.2 degrees
Solar azimuth	63.2 degrees	287.8 degrees	48.3 degrees
Local time	11:04	15:21	10:45
AMG Zone 53	N 7394000 E 353000	N 7393000 E 353800	N 7399000 E 351000

Transect name	**H2A**	**H20A**
	open woodland	open woodland
Date acquired	9/5/01	9/5/01
Flying height AGL	2350 m	284 m
Pixel resolution	1.7 m	0.2 m
Transect bearing	174^{o} magnetic	165^{o} magnetic
Solar zenith	54.7 degrees	41.9 degrees
Solar azimuth	41.4 degrees	10.7 degrees
Local time	10:02	11:51
AMG Zone 53	N 7394000 E 353000	N 7394800 E 353700

Table 2. Details of Landsat TM data used in the CEM Reference Method corrections.

	OW1H	**GTSH**	**GTSH**	**KHMM**
Date acquired	23/10/98	31/12/94	1/12/95	27/4/97
Solar elevation	57.50^{o}	51.79^{o}	51.51^{o}	37.99^{o}
Solar azimuth	72.81^{o}	97.83^{o}	94.78^{o}	48.69^{o}

CEM Reference Method correction approach

The CEM Reference method generates a model using concurrent satellite imagery for each spectral band and assumes that the satellite image does not suffer the same BRDF problem for the same area viewed by the airborne image (Ong *et al.*, (2000a)). The residual product of the airborne and satellite data set is then filtered in the fourier domain to isolate and remove the lower frequency spatial content related to the BRDF variation in the airborne data set. The filtered product is then removed from the original airborne data.

For this study three overlapping video frames from each transect were spatially registered to UTM together with Landsat TM imagery for the same areas. GPS positions were obtained for GTSH, OW1H and H20A transects. The KHMM transect was registered to 10m resolution SPOT Panchromatic imagery. Selected frames from the GTSH transect were corrected by CEM using TM data from two different dates for each frame. Frames from transects OW1H, KHMM and H20A were subsequently corrected by the CSE group after the software became available. Table 3 lists correlations between DMSV bands and TM channels used to determine the most appropriate TM band to use in the correction procedure. Vectors were digitised for input to the BRDF software from the overlap area of frames OW1H16 and OW1H18, and for the overlap area of frames KHMM1 and KHMM6.

For the H20A transect, H2A frame 17 was used as the reference image and was registered to AGM coordinates with a pixel size of 1.8m. Table 4 lists the correlations between the DMSV bands. Vectors were digitized using the overlap area of frames H20A11 and H20A12.

Table 3. Highest correlation coefficients for DMSV mosaics with Landsat TM bands.

	OW1H frames 16, 18, 20		KHMM frames 1, 6, 11	
DMSV band	TM band	Correlation	TM band	Correlation
1	2	0.575	2	0.577
2	2	0.604	2,3,4	0.570
3	4	0.580	3	0.687
4	4	0.612	4	0.508

Table 4. Highest correlation coefficients for transect H20A.

H20A frames 11, 12, 13	H2A frame 17 (reference)	
Band	Band	Correlation
1	2	0.563
2	2	0.631
3	3	0.602
4	4	0.453

CSE correction approach

The CSE correction method is based on the approach of Royer *et al*. (1985) and involves determining averaged bi-directional reflectance variations in each spectral band from a sequence of images along a particular flight line under constant solar illumination conditions. Parameters used in the procedure are described in Pickup *et al.* (1995a) and Pickup *et al.* (1995b). Regressions are used to correct for brightness across the image and a measure of how successful the correction is likely to be is given in the r-squared statistic. Low values tend to occur on transects which have areas of high vegetative contrast (patchiness) or lots of shadow. The correction procedure is largely automated and a transect can be corrected in about an hour.

All three transects were corrected using all 36 frames in each transect to derive regression parameters. R-squared values are shown in Table 5. Transect KHMM was selected for the comparison primarily due to the low r-squared values.

Table 5. R-squared values derived from fitting parameters to average brightness.

Transect	Blue	Green	Red	Nir
KHMM	0.113	0.164	0.015	0.112
OW1H	0.881	0.797	0.860	0.755
GTSSH	0.949	0.947	0.858	0.740
H20A	0.954	0.911	0.824	0.781

Checking the consistency of the CEM and CSE correction approaches

Two approaches were used to check the consistency of spectral values in the frame overlap areas for three frames before and after correction for differential illumination.

1. Adjoining images were classified and class consistency compared in the overlap area in the GTSSH transect only. Images were classified using the supervised Maximum Likelihood procedure in microBRIAN. Class statistics were calculated using a consistent set of training patches (>50) from one frame of each pair which were then applied to both frames to classify the imagery into broad categories such as soil, litter, 'green trees', 'grey trees' and shadow. The proportion of pixels in each category was then calculated for a portion of the overlap area.
2. Statistics were calculated for a range of different areas in the overlap portion of a pair of adjacent frames.

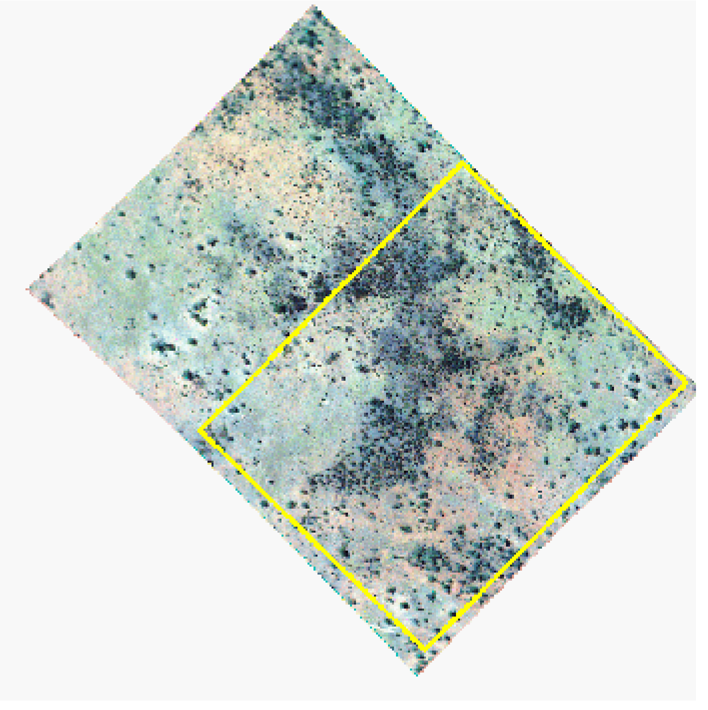

Figure 1. Frame G16 from the GTSSH transect. The yellow rectangle indicates approximately the portion also on frame G18.

Results and Discussion

As similar results were obtained for each of the transects, only a selection is included in this report.

Classification

Table 6 shows the proportion of classified pixels for frames in transect GTSSH in each of the broad soil and vegetation categories in the overlap regions. Results are shown for the uncorrected data, and following correction using the CSE method and the CEM Reference Method with both the 12/94 TM reference image and the 12/95 TM image. Both BRDF correction procedures resulted in an improvement in classification consistency compared with the uncorrected data. The overlap area is outlined in yellow in Figure 1.

Table 6. Percent of pixels classified into broad categories for the same area on frames GTSH16 and GTSH18. (n=25).

	Uncorrected		Correction method					
	RAW		CSE		CEM 12/94		CEM 12/95	
Class	*G16*	*G18*	*G16*	*G18*	*G16*	*G18*	*G16*	*G18*
Soil	4.8	0.8	6.4	5.8	8.4	7.4	8.5	7.7
Soil&litter	61.1	58.1	59.2	58.6	56.3	56.1	54.6	54.4
Litter	18.2	20.0	18.3	19.0	18.6	19.3	20.2	20.8
Whitewood	3.9	4.5	4.5	4.9	5.1	5.6	6.5	7.0
Shadow	2.2	3.5	1.9	2.0	1.5	1.4	1.3	1.2
Mulga	9.2	12.5	9.3	9.4	9.7	9.7	8.5	8.4
Unclassified	0.5	0.7	0.3	0.3	0.5	0.5	0.4	0.4
(n=200900)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Statistics

On each of the transects the overlap portion of a pair of adjacent images was used to calculate statistics before and after correction. Statistics were calculated on 6-8 areas. Figure 2 shows the effect of both correction techniques for pairs of overlapping frames on the transects corrected using Landsat TM reference images. In each case, spectral values in one frame are higher than for the other frame for the same target area on the ground before data correction. This results from the target being imaged in different positions in overlapping frames. After the CEM procedure was applied values were similar in all cases. The CSE procedure resulted in an improvement in the GTSSH frames and the KHMM frames, although the procedure also appears to reduce the spectral values. Table 7 contains the results for frames in the KHMM transect for channel 3. Mean values are similar after correction with the CEM procedure.

Table 7. Means, standard deviations and number of pixels in some areas on the overlapping portion of KHMM frames 6 and 11 channel 3.

		RAW		CEM		CSE	
		Fr 6	Fr 11	Fr 6	Fr 11	Fr 6	Fr 11
Mean	N						
overlap a-rea	99044	69.2	76.6	67.2	66.6	69.2	74.3
mix of tree, grass	4111	50.7	54.2	57.3	55.8	50.7	53.3
mix of tree, bare	4209	79.0	90.3	71.3	72.0	80.0	87.6
heavy tree, shadow	2838	48.4	56.5	47.3	44.7	46.8	53.3
grass	1085	57.8	65.7	60.6	60.3	57.8	64.6
Bare soil	1126	109.1	119.0	104.5	103.3	110.0	117.3
Std. Dev.	N						
overlap area	99044	23.3	24.8	22.3	23.3	23.7	24.6
mix of tree, grass	4111	12.1	12.1	12.1	12.1	12.1	12.1
mix of tree, bare	4209	22.2	23.5	22.1	23.4	22.2	23.6
heavy tree, shadow	2838	12.5	14.3	12.5	14.2	12.7	14.4
grass	1085	11.5	13.2	11.4	12.6	11.5	13.1
Bare soil	1126	7.8	8.6	8.3	9.0	7.8	8.7

Similar results are obtained when the 20cm video data were corrected using 1.8m video data as the reference as shown in Figure 3. The mean values for seven fairly large regions in the overlap area are plotted ranging in size from 736 pixels to 2403 pixels. Both correction techniques resulted in closer spectral values for adjacent frames.

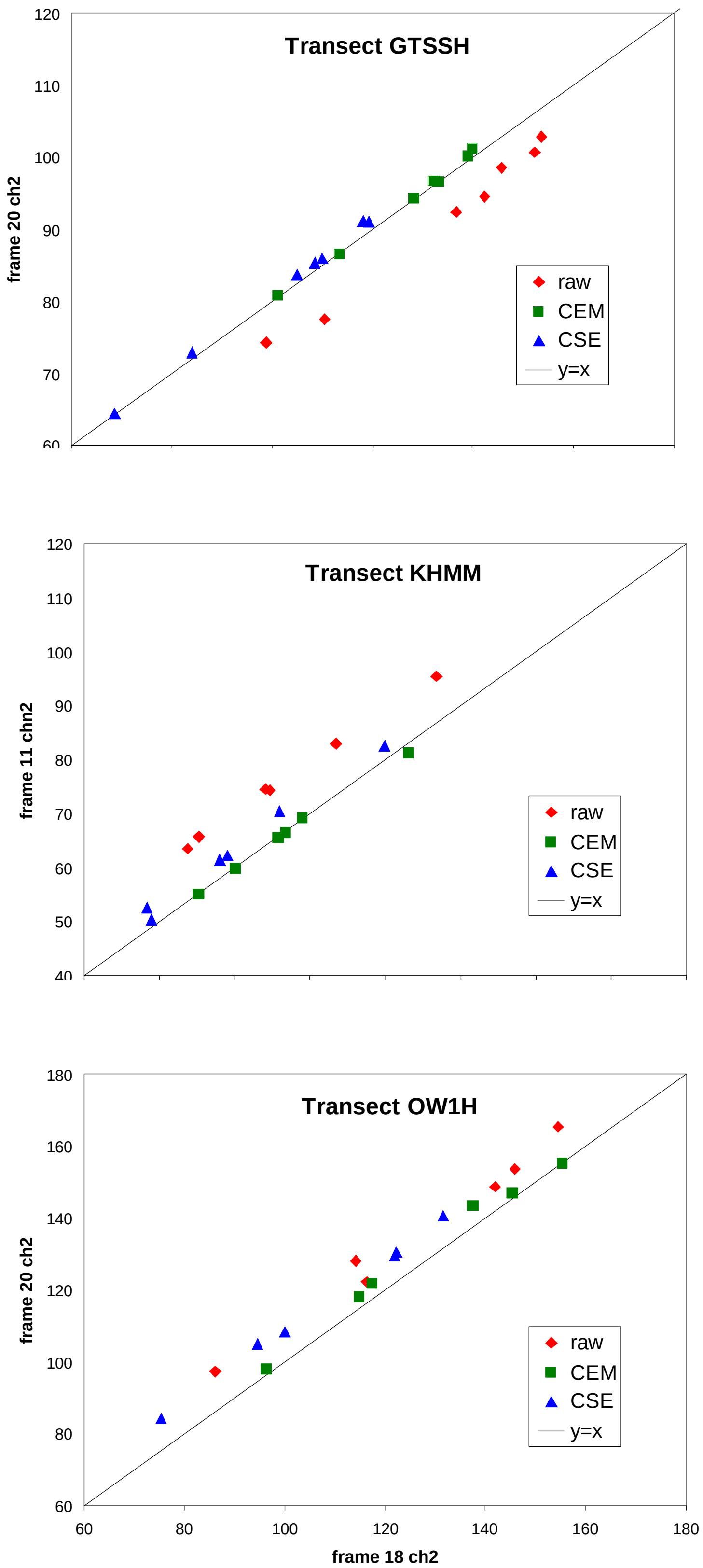

Figure 2. Plots of means (green band) from areas in the overlap portion of adjacent frames on transects corrected using Landsat TM reference images. Uncorrected data, and data corrected with the CEM method and the CSE method are shown.

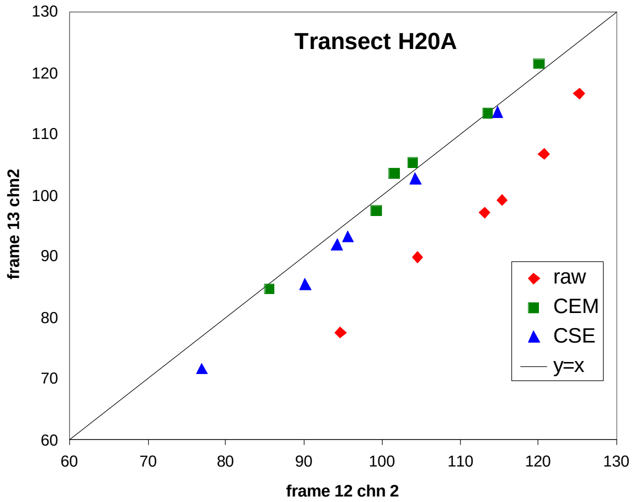

Figure 3. Plots of means (green band) from areas in the overlap portion of adjacent frames on transect H20A corrected using a video reference image. Uncorrected data, and data corrected with the CEM method and the CSE method are shown.

Evaluation of Referencing Method software

The Beta version of the CEM BRDF software tested was received May 14, 2001. A draft of the documentation and sample imagery was also received at that time. Further assistance was provided by Mike Caccetta during the testing stage.

The following steps are needed to implement the CEM Reference Method:

1. Spatially co-register DMSV frames and Landat TM imagery. This is the most time consuming task in the correction procedure.

2. Acquire statistics along the frames to be corrected. This is most easily done in ErMapper. The DMSV frames need to be mosaiced and combined with the TM data. Then correlations are derived between the DMSV bands and the TM bands to find the most suitable TM band to use. The covariance matrix is output for use in the BRDF program.

3. Create several vector files which represent a range of training areas of different cover types from the overlap portion of two frames. At this stage the frames may require 'nudging' to ensure the same areas are selected in both frames. Irregular shaped polygons can be digitized if ENVI is used, if ErMapper regions are used they must be rectangular.

4. Using CEM program BRDF (running in ENVI) determine in interactive mode, the smallest possible filter size which will reduce the brightness difference, below a user specified threshold, for the areas identified in the previous step. This step aims to find a filter which removes the least amount of high frequency data from the original image but still results in a satisfactory scene brightness correction.

5. Apply this filter to the rest of the images in the mosaic by using the batch mode of the program.

Once the images are registered and vector files and statistics calculated the BRDF program is straightforward to use and runs quickly. Each aerial video image takes only a few minutes to correct.

A suggestion for the developers would be to incorporate meaningful error messages which would help diagnosing problems running the software. In particular, some vector files produce an unrecognizable diagnostic.

Recommendations

Most of the aerial video data acquired by the CSE remote sensing group is used for sampling large areas of the rangelands rapidly. We avoid flying at times which are likely to produce a hotspot in the imagery. We have routinely used the CSE correction procedure for about seven years and have found in most cases the results can be adequately classified into broad soil and vegetation categories. In order to use the procedure the transect should consist of a minimum of about 20 images over a fairly similar landscape. For our applications, only a small proportion of the imagery needs to be registered to a map base. This means that the process of registering a number of frames in order to use the CEM Reference Method could add considerably to the time needed to correct DMSV imagery for BRDF effects.

About 20% of the images in the CSE aerial video database have been acquired at a pixel size of 1-2m which can often be registered reasonably accurately to a satellite reference image. The results in this report indicate that the CEM Reference Method produces improved spectral matching using this method. However, most of the imagery in the CSE archive has a smaller pixel size, so Landsat TM imagery is not suitable as a reference. We have also shown that improved spectral matching can be obtained when using video imagery with a larger pixel size as the reference image.

We suggest that the CEM Reference Method be considered when correcting DMSV imagery for bi-directional reflectance effects in the following circumstances:

- The application has a low tolerance for spectral difference in adjacent frames
- The application requires that the DMSV imagery be registered to a map base
- The imagery contains sharp boundaries of contrasting soil or vegetation
- Only a few frames have been acquired

References

Ong, C., Hick, P. and Caccetta, M. (2000). An Integrated Approach to Correction of Scene Brightness Variation in High-resolution Airborne Imagery. Final Report of Stage One of the BRDF Task 3.1. http://www.eoc.csiro.au/

Pickup, G., Chewings, V.H. and Pearce, G. (1995a). Procedures for correcting high resolution airborne video imagery. *International Journal of Remote Sensing* 16, no. 9, 1647-1662.

Pickup, G., Bastin, G.N., Chewings, V.H. and Pearce, G. (1995b). Correction and classification procedures for assessing rangeland vegetation cover with airborne video data. *Procs. 15th Biennial Workshop on Videography and Colour Photography in Resource Assessment*, Terre Haute, Indiana, 305-314.

Royer, A., Vincent, P., and Bonn, F. (1985). Evaluation and correction of viewing angle effects on satellite measurements of bi-directional reflectance. *Photogrammetry Engineering and Remote Sensing* 51, 1899-1914.

Appendix 1. Summary Information About DMSV Imagery

The CSE aerial video database includes 294 transects of DMSV imagery acquired between 1995 and June 1999. The imagery was flown mainly in the rangelands (Table A1).

Table A1. Number of DMSV transects flown in different regions and above different types of country.

Type of Country	Region								Total
	Rangeland						Mine Site	Urban & Forest	
	Alice Springs area	Barkly Tableland	Victoria River District	Coober Pedy area	Oodnadatta area	NE Queensland	Jabiru	SE NSW	
bluebush	13			21	4				38
bluebush swamp		4							4
calcareous shrubby grassland	12								12
creek frontage		5							5
eucalypt woodland		3	49			35	1		88
floodout	1								1
floodplain	8								8
forest								4	4
gibber plain	1				3				4
gidyea woodland	1	1							2
hills	1								1
irrigated lucerne	1								1
lake		3							3
Mitchell grass	8	43	5						56
mountain ranges & gorges	21								21
mulga	8				1				9
open woodland	22								22
river frontage	1								1
sand dune					3				3
spinifex sandplain	5	1							6
targets	2	2							4
urban								1	1
Total	105	62	54	21	11	35	1	5	294