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AN AUTOMATED METHOD FOR PRODUCING REFLECTANCE-ENHANCED LANDSAT IMAGES

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ABSTRACT

For many applications of Landsat data where the skill of a human interpreter is an important part of the data analysis, a high quality image is often more useful than a computer classification of the data. Nevertheless digital processing can usually produce an image which is more easily interpreted than standard, system-corrected photographic products.

We have developed a method to produce a controlled, contrast-enhanced rendition of Landsat data, in which MSS band 4 is displayed as blue, MSS 5 as green, and MSS 7 as red. The two key steps are: (1) a reliable means of transforming Landsat MSS data from radiance units to reasonably accurate reflectance units and (2) a contrast stretch between fixed reflectance limits whose values are determined, for each particular class of application, by independent studies. This gives images which can be reliably intercompared, since unwanted brightness and colour changes caused by atmospheric and illumination effects are removed. The details of these steps are discussed for the cases of application to Rangeland, Forestry, and Geology problems in Canada, and for the problem of providing a superior colour image product for snow- and ice-free scenes in general.

The enhancement method described here can be carried out without input from a specialist on an image by image basis, and with a minimum of decision-making an operator. Images processed by this method are expected to be offered as regular products by the Canada Centre for Remote Sensing.

I INTRODUCTION

For many applications of Landsat data where the skill of a human interpreter is an important part of the data analysis, a high quality image is often more useful than a computer classification of the data. This is because a human interpreter can apply a large amount of additional information and experience to the interpretation. At present, machines cannot routinely duplicate this process. However, digital processing can usually produce an image which is more easily interpreted than standard, bulk-processed photographic products. Considerable effort has already been expended in the production of enhanced images, particularly for the geosciences. Frequently applied enhancements include linear and non-linear contrast stretch[1], band ratios[2], principal components enhancement[1,3], and spatial filtering[4].

In fact the number of possible enhancements for a given scene is very large. For example there are 24 different ways the colours blue, green, and red can be assigned to display three of the four Landsat MSS bands. Consequently, it is difficult to specify an appropriate enhancement for a particular scene and to predict the suitability of this enhancement technique for other scenes.

High quality enhancements have required a substantal amount of customizing by highly skilled personnel[4]. Apart from increasing the cost, this approach has the added disadvantage of introducing artifical differences between one scene and another which result from the subjective enhancement process. This often makes it difficult to determine whether differences between two enhanced images are real or are an artifact of the enhancement.

II DESIGN CONSIDERATIONS FOR AN AUTOMATED ENHANCEMENT

As a result of work at the Canada Centre for Remote Sensing (CCRS) on rangeland[5,6], forestry[7], and geology[8], considerable experience has been gained with enhancements for these applications. Based on this experience we attempted to define an enhancement technique which would have wide applicability and low operational cost. The criteria we emphasized are discussed individually below.

1. The enhancement should portray a particular ground cover class consistently from one scene to another without being altered by enhancement parameters which vary due to changes in scene statistics or subjective choices made by an operator or analyst.

2. The way in which the scene is portrayed should not represent a radical departure from images currently used by environmental scientists. Our experience in introducing remote sensing products and methods to new users has shown that users already familiar with colour infrared aerial photography can readily adapt to the traditional colour assignment of Landsat MSS data in which MSS 4 is displayed as blue, MSS 5 is displayed as green, and MSS 7 is displayed as red. In contrast, enhancements which result in radically different looking images (such as reference 3) require much more training to interpret. As we sought a product with the widest possible acceptability, we decided to base the enhancement on the traditional rendition of MSS data.

3. The enhancement should offer the possibility of automation. Automation would avoid the cost and subjectivity associated with having a skilled environmental scientist or technologist make decisions about each image to be enhanced.

4. Confusing effects unrelated to the desired scene information should be minimized. The most important confusing effects are illumination variations, atmospheric variations, and photographic variations.

The enhancement chosen to achieve these requirements consists of a contrast stretch of Landsat MSS band 4, 5, and 7 data between pre-determined reflectance limits, followed by colour rendition with MSS 4 displayed as blue, MSS 5 as green, and MSS 7 as red.

The transformation to reflectance units results in the removal of undesirable illumination and atmospheric variations. The use of pre-defined limits means that the photographic portrayal of a ground cover type with specific reflectance characteristics always has the same brightness, hue, and saturation, within the tolerance incurred in the photographic process. The use of traditional colour assignments results in imagery which can be easily interpreted by persons familiar with the false colour infrared representation. Finally, the process lends itself to automation since there is no decision required from an operator.

Good photographic quality control is required to produce a consistent product. A tolerance of 0.1 density over a density range of 0.2 to 1.6 has been found to be achievable and to produce products of consistent colour and brightness.

III. PRODUCING THE ENHANCEMENT

A. THE PROCESS REQUIRED TO PRODUCE THE ENHANCEMENT

The enhancement defined in the previous section can be described in terms of a linear transformation between the original digital value of each pixel, D, (0 - 255 scale), and a new digital value, D'.

$$D' = AD + B \qquad (1)$$

The calculation of the coefficients A and B incorporates three separate linear effects:

1. The transformation from LANDSAT digital units (D) to radiance units (L)[9]:

$$L = D\,A_1\,10^{E_1} + A_0\,10^{E_0} \qquad (2)$$

where L is radiance in $w/cm^2 sr$ and A_o, A_1, E_o, and E_1 are constants defined in the original calibration of the data.

2. The transformation from radiance units (L) to reflectance units (R)[13]:

$$R = \frac{\pi(L - L_p)}{HT} \qquad (3)$$

where L_p is the atmospheric path radiance, H is the total downwelling irradiance in w/cm^2, and T is the atmospheric transmission (dimensionless).

Once L_p, H, and T are known, it is possible to define a transformation between reflectance units to new values D'

$$D' = 255 \frac{R - R_{min}}{R_{max} - R_{min}} \qquad (4)$$

where D' is truncated at 0 and 255 outside of this linear range. (Please note that R_{max} and R_{min} refer to reflectance limits rather than radiance limits as in Ahern and Murphy[9]. Since the latter publication was produced, the International Society of Photogrammetry and Remote Sensing has chosen R as the symbol for reflectance factor, while L (as well as N) is a commonly used symbol for radiance.)

Combining (2), (3) and (4) we have:

$$D' = \frac{255\pi A_1 10^{E_1}}{(R_{max}-R_{min})HT} D + \frac{255}{(R_{max}-R_{min})}\left[\frac{\pi(A_o 10^{E_o} - L_p}{HT} - R_{min}\right] \qquad (5)$$

Comparing (5) with (1) we see that

$$A = \frac{255\pi A_1 10^{E_1}}{(R_{max}-R_{min})HT} \qquad (6)$$

and

$$B = \frac{255}{R_{max}-R_{min}}\left[\frac{\pi(A_o 10^{E_o} - L_p)}{HT} - R_{min}\right] \qquad (7)$$

B PROBLEM AREAS

The variables required to derive values for A and B in equations (6) and (7) can be grouped into three categories: calibration constants, variables describing the illumination and atmospheric conditions, and reflectance limits for the desirecd enhancement. The calibration conetants are time-invariant as defined in the NASA and CCRS production systems.[9]

1. <u>Illumination and Atmospheric Corrections</u>

1.1 Testing a standard atmosphere

The illumination of the scene (total downwelling irradiance, H) is primarily a function of the solar zenith angle and the earth-sun distance. Changes in atmospheric conditions due to variable aerosol scattering have negligible effects on H for conditions clear enough to secure usable images.

The path radiance, Lp, and the atmospheric transmission, T, are more difficult to determine accurately. These two variables are not independent but rather are linked through the equation of radiative transfer[13]. A study of atmospheric variability over Canada was conducted to judge whether the use of standard atmospheric conditions would provide an adequate determination of Lp and T, as suggested by Richardson.[10] The details of our study are reported elsewhere[14]. The principal objective of our study was to determine whether the variations in image brightness, contrast, and colour introduced by atmospheric variablility would significantly impede the interpretation of the enhanced images, particularly when multi-location and multi-temporal comparisons were being made.

A sample of 36 Landsat MSS scenes was used to determine a mean value and a standard deviation of Lp and T. These values were used to estimate the changes in brightness and colour introduced into the rendition of four distinct rangeland classes by atmospheric variability[14]. Figure 1 is a colour prediction diagram showing the expected atmospheric effects on enhanced imagery. It can be seen that under worst-case conditions ($\pm 2\sigma$ changes in the atmosphere about the average (standard) condition), the colour of areas of dense forbs (broad-leaf plants) and shrubs (A) would change from red to pink, and the brightness of areas of good rangeland (C) and crested wheatgrass (D) would change significantly.

Test images produced to simulate these cases bore out this evaluation and showed unacceptably large brightness, contrast, and colour variations. Therefore it was concluded that the use of standard atmospheric conditions could not be used for successful automation of the rangeland enhancement.

1.2 Testing the use of the histogram lower bound

A number of authors[4,12] have used the lower limits of the histogram of each band (histogram lower bound or darkest pixel) as an indication of haziness of Landsat scenes. Since the histogram of a band depends on the reflectance factors of the objects in the scene (scene content) as well as the haziness of the atmosphere, this method must be approached with caution when one needs a technique which will work reliably for many scenes and without the need for human judgment.

An inspection of many of the 36 scenes selected for measuring atmospheric variability indicated that the darkest pixels in bands 6 and 7 are invariably water bodies. Since light does not appreciably penetrate water at these wavelengths, it is reasonable to expect that all water bodies have the same reflectance factor, within ±1% or less, in these bands. Since surface water exists throughout Canada during the snow- and ice-free season, the histogram lower bound can give a good indication of path radiance in bands 6 and 7 for nearly all snow- and ice-free Canadian scenes. In bands 4 and 5 the darkest pixels were generally associated with dense green vegetation in these scenes although in mountainous terrain and in scenes with cumulus clouds, the shaded slopes and cloud shadows were a few digital levels darker. This latter difference has a negligible effect on the final image. Because dense green vegetation can also be expected in most snow- and ice-free Canadian scenes, and because spectroscopic studies by us[15] and others indicate that the reflectance factor of dense green vegetation is nearly constant, it appears that the histogram lower bound can also give a reasonable indication of path radiance in these bands.

A regression analysis was performed between the histogram lower bound and the independently determined path radiance in each of the 36 sample scenes[14]. The coefficients of determination indicated that the location of the histogram lower bound accounts for 91% of the variance of the MSS 4 and MSS 5 path radiance, 84% of the variance of the MSS 6 path radiance and 82% of the variance of the MSS 7 path radiance. Sources of variance not accounted for include variability of path radiance across the scene, random (speckle) and systematic (striping) radiometric errors, variability of the reflectance factors of the darkest pixels in the various scenes, and (particularly for MSS 7) quantization noise. This study convinced us that the use of the histogram lower bound can yield an estimate of path radiance which could remove most of the errors caused by atmospheric variability. Figure 1 shows how using the histogram lower bound to estimate the atmospheric conditions of a scene can reduce the variability of the rangeland enhancement.

Test photographs indicate that the variability of brightness, contrast, and colour in the rangeland enhancement is insignificant when the histogram lower bound is used to estimate atmospheric conditions for the transformation to reflectance units.

2. Reflectance Limits for Specific Enhancements

Equation (3) can be employed to convert Landsat MSS data to reflectance factor values. Uncertainties in the parameters used for the radiometric calibration and atmospheric correction will introduce systematic errors in the resulting reflectance factors.[13] These do not vary significantly with time and do not affect the enhanced images significantly.

The reflectance limits for the rangeland enhancement were chosen from reflectance factors measured on the ground and from reflectance-corrected Landsat data.[5,6] Minor adjustments have been performed more recently to increase the average brightness of the mixed grass prairie and to avoid changing the limits of MSS 7 for September and October imagery.

The reflectance limits for the standard and forestry enhancements were determined by calculating the reflectance factors of individual objects in a number of test scenes, and by calculating the reflectance factors corresponding to the upper and lower limits of intensity values of interest in the histograms of these test scenes. Equation (3) was used for these calculations. Minor adjustments may be necessary after producing test images on a hard copy device. The reflectance limits used for the production of the enhanced images will be included in the image annotation and documented in a users' guide.

The forestry enhancement has been optimized to emphasize differences between such cover types as hardwoods, softwoods, mixed woods, burned areas, cutover areas and regrowth. MSS 5 is displayed with very high contrast to increase the visibility of narrow logging roads and other human disturbances.

The standard enhancement is designed to provide a good rendition of a wide variety of snow- and ice-free scenes of Canada. As such it will not provide the optimum rendition of any particular scene but instead is offered as a relatively inexpensive product which is superior to the standard system corrected colour composite which has been available until now.

An evalution of several scenes of geological interest indicated that fixed reflectance limits would not satisfy geological requirements.[16] Geologists are often more interested in emphasizing structual information, evident as shapes and patterns in imagery, rather than ground cover types which are evident through their reflectance characteristics. On the other hand, scene-to-scene consistency is less important to a geologist. Hence a geologist requires the ability to customise an enhancement to bring out the features of interest in a particular scene. To accomodate this requirement a custom enhancement is offered (Table 1) in which the user can specify lower and upper limits, either in terms of digital values on a 0-255 scale or as reflectance factors. It must be emphasized, however, that the geologist may need to see the effects of various enhancements on a video display to achieve the desired results. This means that the production of a satisfactory enhancement for geology will not, at present, satisfy the objectives of low cost and rapid turnaround which we have achieved for the standard, rangeland, and forestry enhancements.

3. Automated Detection of the Histogram Lower Bound.

Automating the detection of the histogram lower bound would be desirable to avoid subjective judgments. This is not essential, however, since it is quite straightfoward to display the lowest 30 to 40 digital levels (0-255 scale) in each band on an alphanumerics terminal and allow the operator to select the lower bound of bands 4, 5, and 7. The main problems in automating this detection result from the possibility of spurious values caused by data errors, and from gaps in the histogram sometimes introduced in converting from the 64 grey levels of the raw data to the 256 grey levels of the radiometrically corrected data.

An automated detection of the histogram lower bound has been devised which works well if there are no more than 9 bad pixels in any level of the histogram, and if gaps do not occur near the histogram lower bound. The histogram lower bound is designated as the lowest digital value for which the histogram is non-zero and for which there are at least 10 pixels in at least three of the four levels consisting of it and the next three higher levels. At present an operator is required to confirm the detected histogram lower bound and override the choice if the automated detection has failed.

IV PRODUCTION SYSTEM AND PRODUCTS OFFERED

Based on the above results, the production of imagery with the standard, rangeland, forestry, and custom enhancements is being developed into an operational, highly automated system. Table 1 indicates the characteristics of the system. Enhanced Landsat MSS imagery produced with the techniques described in this paper are expected to be offered by the Canada Centre for Remote Sensing.

Manually produced forerunners of these products have been used operationally to monitor rangeland utilization in Alberta and Saskatchewan and to monitor forest changes in Nova Scotia.

V. SUMMARY AND CONCLUSIONS

We have developed an automated method to produce a controlled, contrast-enhanced rendition of LANDSAT data, in which MSS band 4 is displayed as blue, MSS 5 as green, and MSS 7 as red. The two key steps in this method are: a reliable means of transforming Landsat MSS data from radiance units to reasonably accurate reflectance units, and a contrast stretch between fixed reflectance limits whose values are determined, for each particular class of application, by independent studies. This gives images which can be reliably intercompared, since unwanted brightness and colour changes caused by atmospheric and illumination effects have been removed.

Enhancements optimized for forestry and rangeland have been developed. A standard enhancement for all snow- and ice-free Canadian scenes has also been developed. An automated system to produce these enhancements is being implemented.

Geological interpretation generally requires a custom enhancement which can be produced with the automated system if the appropriate radiance or reflectance breakpoints can be specified independently.

Images processed by these techniques are expected to be offered as products by the Canada Centre for Remote Sensing.

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Table 1

Characteristics of CCRS Enhancement Production System

Enhancements Offered

- Standard
- Rangeland
- Forestry
- Custom
    - specified from intensity (0-255 scale) limits
    - specified from reflectance limits

Input products

- Universal (JSC) format CCTS
- Standard (LGSOWG) format CCTS
- Precision corrected (DICS) CCTS

Output products

- 1:10^6 colour negatives
- positive prints (paper and transparency) at scales of:

1:1,000,000
1: 500,000
1: 250,000

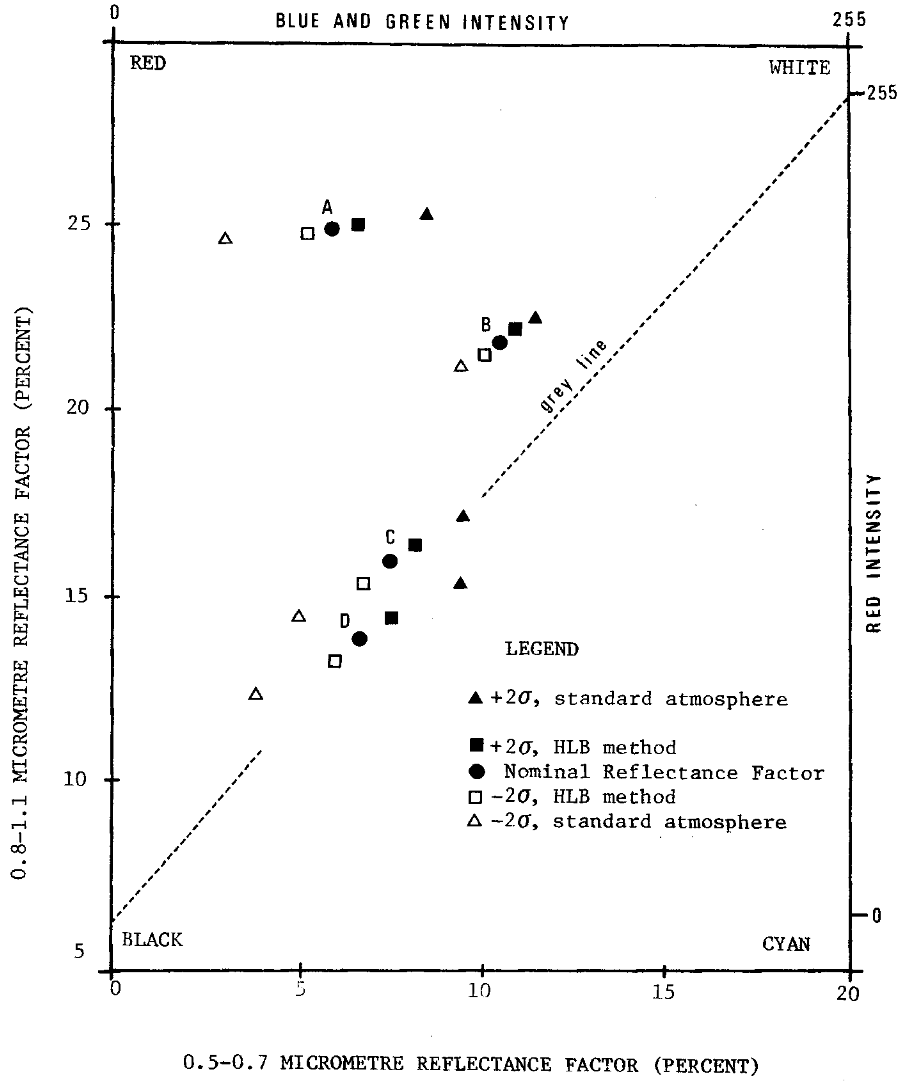

FIGURE 1. Colour Prediction Diagram showing effects of errors in atmospheric correction for rangeland enhancement with four rangeland classes. The nominal reflectance factor is shown by ●. Under the assumption of standard atmospheric conditions, the estimated reflectance factor will lie at the point indicated with ▲ when the actual atmosphere is two standard deviations hazier than standard conditions, and at △ when the actual atmosphere is two standard deviations clearer than standard condition. Using the histogram lower bound method to estimate the atmospheric conditions the estimated reflectance factor will lie at the point indicated with ■ where the actual atmosphere is hazier than the estimate and at □ when the atmosphere is two standard deviations clearer than the estimate.

A = dense forbs and shrubs, B = poor rangeland site

C = good rangeland site, D = crested wheatgrass

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Dr. Keith P.B. Thomson graduated in honours physics from Queens University Belfast. He took his masters degree in meteorology and doctorate in Atmospheric Physics at the University of Toronto. Dr. Thomson has been active in various fields of environmental science. He became active in remote sensing in 1970 and has been with the Canada Centre for Remote Senisng since 1974. Dr. Thomson is currently a research scientist at CCRS and has published extensively in remote sensing and related fields.

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