Cloud-Shadow Suppression Technique for Enhancement of Airborne Thematic Mapper Imagery*

Abstract

Airborne Thematic Mapper (ATM) data are often degraded by the shadows from clouds above the aircraft during the flight. The spectral information in cloud-shadowed areas is reduced but not totally lost because the reflected energy of diffuse illumination (sky light) reaches the sensors from the shadowed ground despite obstruction of direct solar radiation. The thermal band image is almost unaffected by the temporary change of radiation caused by clouds. An enhancement technique for cloud-shadow suppression has been developed based on differencing, RGB-HSI-RGB transformation, and thermal band modulation. The method suppresses cloud shadows with topographic shading retained; spectral information is retrieved and enhanced. The result is a nearly normal color composite with full topographic expression but without cloud shadows. Such a color composite is easy to interpret for geological structures and lithologies.

Introduction

A Daedalus Airborne Thematic Mapper (ATM) image representing part of the Natural Environment Research Council (NERC) geoscience test site in southeast Spain was found to be degraded by patchy shadows caused by clouds above the aircraft during the flight. The shadowed areas suffer from serious spectral information loss and are present as dark patches in all ATM band images except the thermal band (Band 11). This kind of problem is not uncommon because an airborne remote sensing flight has to be pre-arranged, and clear sky over the mission area on the day of the flight cannot be guaranteed. Cloud shadows can make large portions of the images unusable. It is, therefore, worthwhile to investigate possible methods to restore the image information for cloud-shadowed areas.

Contrast enhancement and image-spectral profiles reveal that some spectral information is still preserved in the shadowed areas though it is weak and spectrally distorted. Figure 1 shows 11 band ATM image spectral profiles of several locations in cloud shadows and nearby unshadowed areas. The spectral shapes of similar terrain types are similar in reflective spectral bands (Bands 1 to 10) both within and outside cloud shadows, although the average DN (Digital Number) levels of the two cases are different. This is because the reflected energy of diffuse illumination reaches the sensors from the shadowed areas despite the direct solar radiation being obstructed by the clouds above the aircraft. The variation of DNs in the thermal band (Band 11) does not coincide with that of other bands because DNs in day time thermal images are mainly decided by sustaining incident solar radiation and not obviously affected by the shadows of moving patchy clouds.

In addition to cosmetic image improvement, restoration of cloud-shadowed images for geological interpretation has two objectives. First, cloud shadows should be suppressed but topographical shading retained to illustrate the relationship between terrain and geological structure. Second, any spectral information from shadowed areas should be retrieved to assist in understanding rock, soil, and vegetation relations. The objective of the restoration procedure should be to generate a color composite similar to the one of the three original bands but with cloud shadows suppressed.

This paper describes a simple technique to meet these requirements. The technique is based on image differencing, RGB-HSI (Red Green Blue - Hue Saturation Intensity) transformation, and thermal band modulation.

Methodology

Considerations for Technique Design

Examination of all the bands of the ATM data set used for this study shows that the thermal band (Band 11) presents topography well and is almost unaffected by cloud shadows (Figure 2a). This is because the daytime thermal emission of the ground changes little with temporary changes of incident solar radiation, such as those caused by shadows of moving and changing cloud patches. To make the temperature change detectable by the ATM thermal sensor, earth material needs longer to warm up or cool down than moving cloud shadows allow. Thus, the thermal band can be used to restore topographic features in cloud-shadowed areas.

The approach is based on an RGB-HSI-RGB transformation. An RGB-HSI transformation of a color composite converts spectral variation to the hue component and illumination variation (shadows and topography) to the intensity component (Figures 2b and 2c). Because the hue image is shadow free (Liu, 1990), the HSI-RGB transformation with the intensity component being replaced by the thermal band may suppress cloud shadows without damaging topographic features. Unfortunately, such a simple approach is not successful because the saturation component

*Presented at the Ninth Thematic Conference on Geologic Remote Sensing, Pasadena, California, 8-11 February 1993.

Photogrammetric Engineering & Remote Sensing, Vol. 59, No. 8, August 1993, pp. 1287–1291.

0099-1112/93/5908–1287$03.00/0

Liu Jian Guo
J. McM. Moore
Centre for Remote Sensing, Imperial College, London SW7 2BZ, United Kingdom.

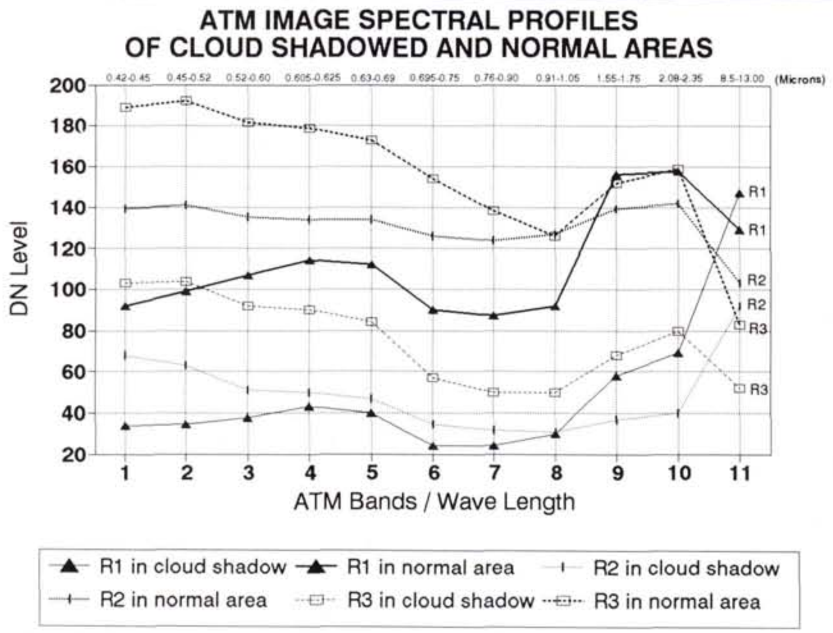


Figure 1. Image spectral profiles of 11 ATM bands of the test subscene in southeast Spain. The profiles are based on the average DNs of pixels in a square box with five pixels on each side. The thin line profiles represent locations in cloud shadows and the thick ones represent locations in adjacent unshadowed areas.

is not independent of intensity (Smith, 1978; Schowengerdt, 1983) and is, therefore, affected by cloud shadows. The image of saturation shows that the color saturation of shadowed areas is higher than that of normal areas (Figure 2d). This is because saturation is inversely related to intensity according to the simple mathematical model of an RGB-HSI transformation (Smith, 1978). In order to generate hue and saturation components both free of cloud shadows, shadows must be suppressed for each of the three bands of a color composite before the RGB-HSI transformation.

Both multispectral image band ratios (Sabins, 1978) and differencing (Castleman, 1979) are effective methods to suppress topographic shadows and remove common background features. Cloud shadows can also be suppressed by these techniques. If the same band is used as the denominator or subtrahend for all the three bands when applying ratio or differencing for shadow suppression, the spectral relationship among the three bands used for the color composite will be preserved and the hue information of the color composite will be unchanged (Liu, 1990).

In the case of differencing, if the same band, D, is subtracted from each of the three bands of a color composite (*red*, *green*, and *blue*), then, for a pixel, $P(i,j)$, value $d(i,j)$ will be subtracted from its DN value in each of the three bands: i.e.,

$$
\begin{aligned}
red(i,j) &- d(i,j) \\
green(i,j) &- d(i,j) \\
blue(i,j) &- d(i,j)
\end{aligned}
$$

This is equivalent to vertically shifting the spectral profile of this pixel downward by $d(i,j)$ DN levels. The shape of the profile is thus unchanged. The operation does not change hue but modifies saturation. Generally, this kind of differencing decreases the intensity of bright areas and increases the color saturation. This property balances color saturation among the areas with different illumination and is, therefore, favorable to eliminating cloud shadows in the saturation component derived from the difference color composite by the RGB-HSI transformation. In interactive difference processing, the optimal shadow suppression can be achieved by adjusting the weights of the two images for differencing, based on visual judgement. An effective shadow suppression in three difference images means an effective shadow suppression in both intensity and saturation components derived in turn.

Ratios using the same band as denominator for the three bands of a color composite changes the shapes of spectral profiles but does not change either hue or saturation. Therefore, it may not be effective for eliminating cloud shadows in the saturation component derived from a ratio color composite by the RGB-HSI transformation. Because a ratio is a two-dimensional transformation from a Cartesian coordinate system to a polar coordinate system, the resulting image should be stretched by the arctangent function rather than by a linear scale. This increases the complexity of processing and makes interactive processing difficult. Experimental results show that ratios are less effective and efficient than differencing for cloud-shadow suppression. Differencing has, therefore, been chosen for shadow suppression in this study.

A difference color composite image may suppress cloud shadows and enhance some spectral features, but it is difficult to understand for general geological interpretation because it lacks topographic features (i.e., terrain shadings). Topographic information can be re-introduced by the RGB-HSI-RGB thermal modulation procedure.

Following the above discussion, a three-step cloud-shadow suppression technique for enhancement is introduced in the next subsection.

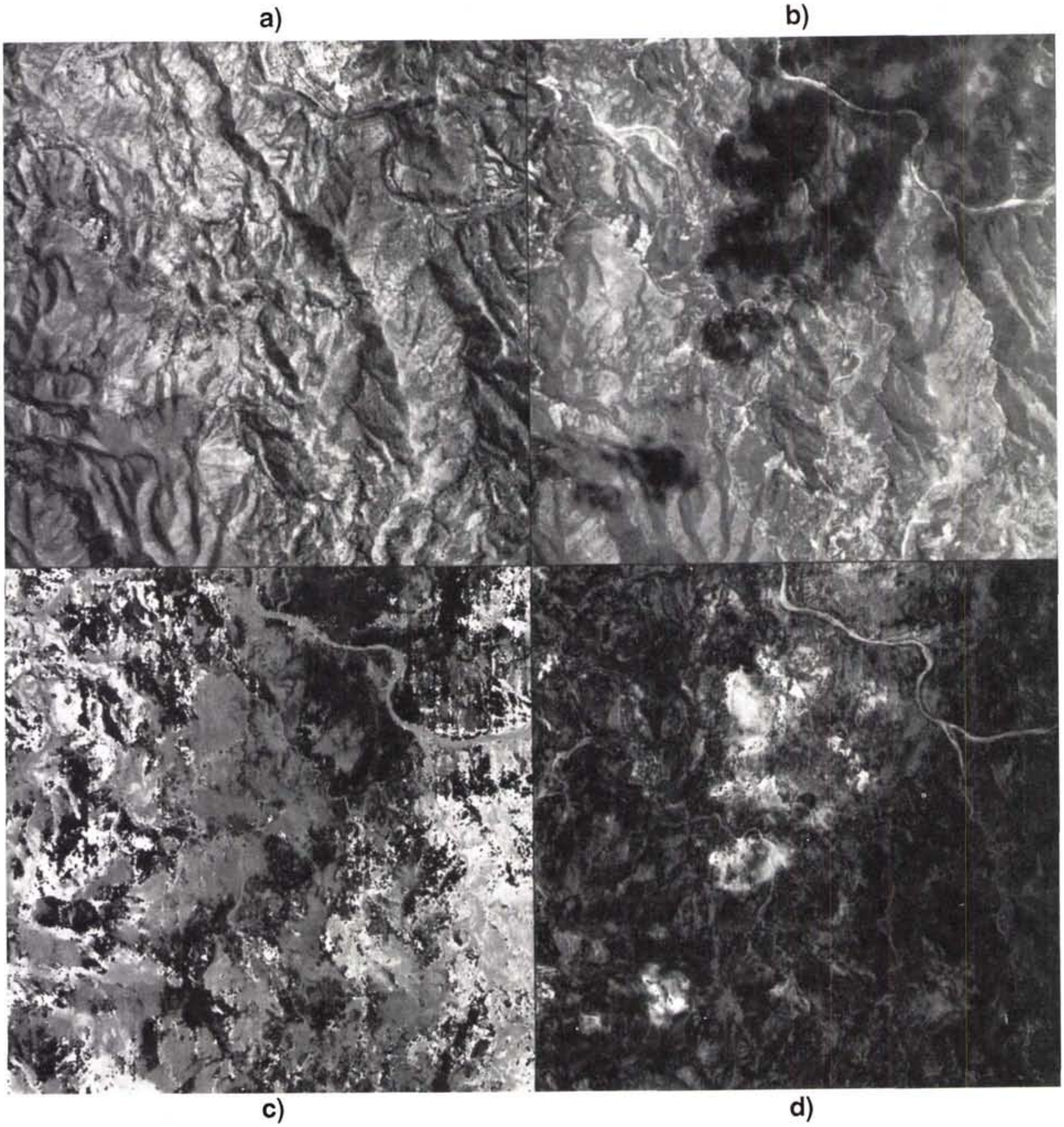


Figure 2. ATM images of test subscene in southeast Spain. (a) The thermal band image (Band 11). (b) The intensity component of the color composite of ATM Bands 9, 4, and 2 in red, green, and blue. (c) The hue component of the same color composite. (d) The saturation component of the same color composite.

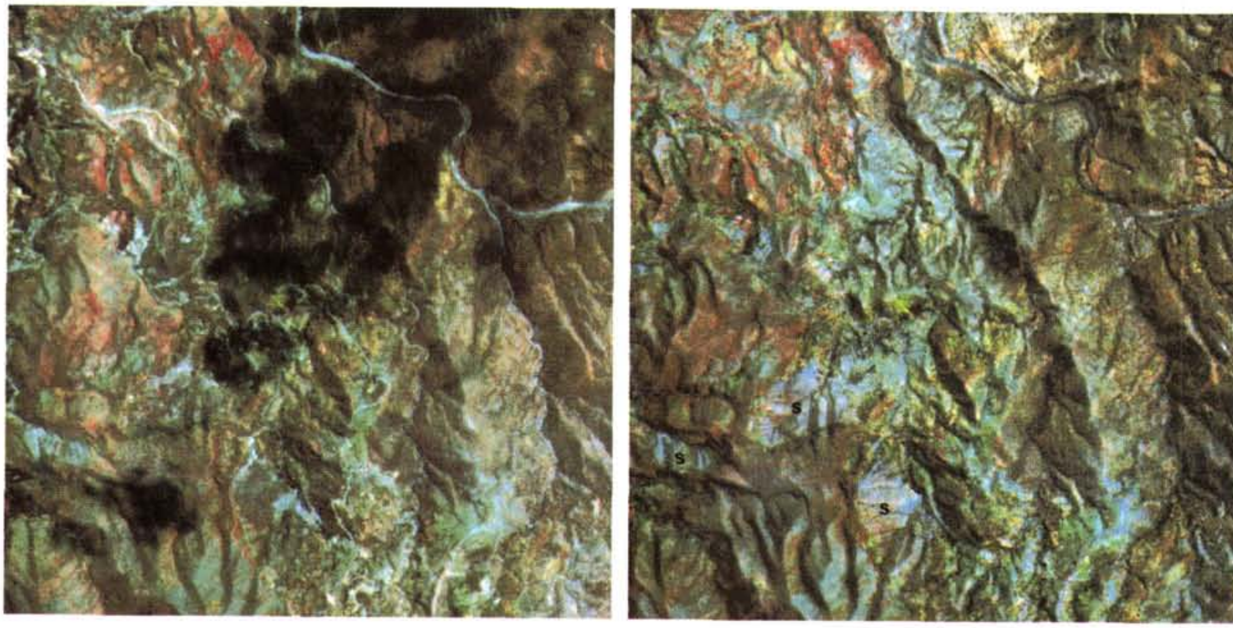
Cloud-Shadow Suppression Technique for Enhancement

Step 1. General Shadow Suppression

Subtract the same band from each of the three bands used for a color composite to produce three difference images. This process suppresses both topographic and cloud shadows. The average image of the three bands, which is equivalent to their intensity component, can be used as the subtrahend image. A more interesting approach is to select another band as the subtrahend to enhance particular spectral features in addition to shadow suppression. The band selection for the subtrahend depends on enhancement targets, but it is preferable that the subtrahend band have relatively low correlation with each of the three bands of the color composite. Otherwise, the SNR (signal-to-noise ratio) of the resulting differencing images may become too low. This step generates a difference color composite with spectral information enhanced, but with topography, as well as cloud shadows, suppressed.

Step 2. RGB-HSI Transformation of Difference Images

Transform the three difference images produced in Step



(a) (b)

Plate 1. Color composites of the ATM test subscene. (a) Color composite of Bands 9, 4, and 2 in red, green, and blue. (b) Color composite produced by cloud-shadow suppression enhancement. (The letter **s** indicates serpentine.)

1 to hue, saturation, and intensity images. In order to increase the spectral contrast among the three difference images and concentrate maximum spectral information in the later derived hue image, the balance contrast enhancement technique (BCET) (Liu, 1991) can be applied to balance the contrast and brightness of these difference images before the RGB-HSI transformation. The effects of cloud shadows are effectively suppressed in the hue and saturation images, which will be used in the next step.

Step 3. Thermal Band Modulated HSI-RGB Transformation

Replace the intensity image with the thermal band and then perform the HSI-RGB transformation to convert the hue, saturation, and thermal band (used as a pseudo intensity component) back to red, green, and blue images relevant to the three bands of the original color composite. Thus, the thermal band modulates the hue and saturation information of the difference images and brings back topographic features to the final product. The final image is a color composite retaining the composite spectral information of the three difference images, but with topographic shading re-introduced by the thermal image. The image resembles the original color composite but with cloud shadows suppressed.

Example

A 512 by 512 subscene of the ATM data supplied by the National Environment Research Council (NERC) for the geoscience test site in southeast Spain was processed to test the technique.

Plate 1a is a color composite of ATM Bands 9, 4, and 2 displayed in red, green, and blue using the BCET. This band combination is generally good for lithological interpretation in this area, especially for clay rich mineral alteration, iron oxide, and red soils. The areas in bright red, such as the small circular feature in the top left part of the image, represent iron deposits in Triassic dolomites. The image has cloud shadows that interrupt and conceal the spectral and spatial image features.

ATM Band 8, which highlights vegetation as well as lithological variation and has relatively low correlation to Bands 9, 4, and 2, was used as the subtrahend image to generate three difference images, ATM9-ATM8, ATM4-ATM8 and ATM2-ATM8. RGB-HSI-RGB thermal band modulation was then applied. Finally, a color composite (Plate 1b) was produced. The spectral and spatial information of the original color composite is restored well in Plate 1b. It resembles Plate 1a but with cloud shadows effectively suppressed and the spectral and spatial features blocked by cloud shadows retrieved. The iron-oxide deposits and clay-rich outcrops and soils are enhanced and clearly illustrated in red colors. Serpentine, a lithology that is not very distinctive in the original color composite, is particularly well displayed (marked by **s** in Plate 1b). Because the vegetation band, ATM8, was used as the subtrahend image for every band, the vegetation is clearly illustrated as black spots and patches in Plate 1b. This is information that the original color composite (Plate 1a) does not provide.

Plate 1b shows a higher overall saturation than Plate 1a because of the difference processing. This generally enhances spectral (color) features of the image but may damage the information presented by variation of saturation because the saturation of the image has been somehow equalized by differencing. For instance, a bright feature near the river in the upper right part of Plate 1a becomes indistinguishable in Plate 1b. The spectral information is not retrieved perfectly because the method cannot correct the spectral distortion caused by cloud shadows. As a result, colors of shadowed areas in Plate 1b may be subdued. Therefore, the image should be used with caution.

A color composite of ATM Bands 10, 4, and 1 in red, green, and blue was also processed for cloud-shadow suppression. The average image of the three bands was used as the subtrahend image in Step 1. In this case, the cloud shadows were suppressed effectively, but the color variation was less than the original composite, as the color saturation was equalized by the differencing process.

Experiments with several subscenes indicate that using a spectral band with low correlation to the three bands of a color composite as the subtrahend rather than the average image of the three bands achieves better spectral enhancement in cloud-shadow suppression processing.

Conclusions

Cloud-shadowed areas in ATM imagery may preserve some spectral information because the reflected energy of diffuse illumination reaches the sensors from the shadowed areas despite the direct solar radiation being obstructed by the clouds above the aircraft. The thermal band of ATM is almost unaffected by cloud shadows as the clouds are not usually stationary long enough to cause surface temperature change in the cloud-shadowed areas.

In order to improve the geological interpretation of images obscured by cloud shadows, a technique has been developed based on differencing and thermal band modulation to suppress cloud shadows and restore the spectral and spatial features in shadowed areas. The technique comprises three steps:

- Production of three difference images by subtracting the same band from each of the three bands of a color composite. This preserves the composite spectral information and suppresses both topographic and cloud shadows.
- Transformation of the three difference images into HSI space. Spectral information is thereby stored in the hue and saturation components.
- Replacement of the intensity component by the thermal band. (This image is almost unaffected by cloud shadows and has good topographic expression.) The HSI-RGB transformation is then performed to produce a new color composite image.

The resulting image is a color composite retaining the spectral information of the original color composite, together with topographic shading introduced by the thermal image.

Subscenes of the ATM image covering the Natural Environment Research Council (NERC) geoscience test site in southeast Spain were processed using the technique. Cloud shadows were effectively removed, and both spectral and spatial information in shadowed areas was successfully restored. The technique may cause minor spectral information loss because of equalized saturation by differencing, but the spectral information loss can be minimized by using a carefully selected spectral band as the subtrahend for differencing. The cloud-shadow suppressed image is much more satisfactory for geological interpretation than the original ATM data.

Acknowledgment

The Natural Environment Research Council (NERC) is gratefully acknowledged for providing the ATM data used in this study.

References

Castleman, K. R., 1979. *Digital Image Processing*, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, pp. 96–108.

Liu Jian Guo, 1990. Hue image colour composition - a simple technique for shadow suppression and spectral enhancement. *International Journal of Remote Sensing*, 11:1521–1530.

———, 1991. Balance contrast enhancement technique and its application in image colour composition. *International Journal of Remote Sensing*, 12:2133–2151.

Sabins, F. F., Jr., 1978. *Remote Sensing: Principles and Interpretation*, W. H. Freeman and Company, New York, pp. 258–263.

Smith, A. R., 1978. Colour gamut transformation pairs. *Proc. SIGGRAPH'78 Conference*, 23-25 August, Atlanta, Georgia, pp. 12–19.

Schowengerdt, R. A., 1983. *Techniques for Image Processing and Classification in Remote Sensing*, Academic Press, New York, London, pp. 117–126.