ANALYSIS OF VIEW-ANGLE EFFECTS IN HYPERSPECTRAL DATA OF URBAN AREAS

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ABSTRACT:

Data from the Hyperspectral Mapper (HyMap), which is acquired with a field of view (FOV) of 61.3 degrees, is disturbed by the bidirectional behavior of the covered surface and its complex geometry. The resulting phenomena, an across-track brightness gradient and spectral differences caused by shifted objects, were described and analyzed in detail. An appropriate correction method for the object shift does not exist; its influence on the spectral information is severe, though, due to the great illumination differences caused by facades that are visible at large view angles. These either very bright or dark facades require the user to take into account the resulting spectral influences. Concerning the brightness gradient, it was shown that different surfaces have different bidirectional properties and a correction thus requires an approach, where an individual correction function is fit to each surface type.

1. INTRODUCTION

Current airborne hyperspectral imaging sensors acquire data with a wide FOV to cover large areas even at low operating altitudes. In the case of HyMap, the FOV of 61.3 degrees induces view-angle dependent effects like an across-track brightness gradient and object shift, both of which are especially noticeable in data acquired over urban areas.

The across-track brightness gradient is caused by bidirectional effects of the scanned surfaces. Common correction routines use a global correction function that does not account for surface dependent bidirectionality. Kennedy et al. (1997) and Beisl (2001) suggest approaches where individual correction functions are fit to different surface types in HyMap and AVIRIS data. Such approaches seem especially suited for urban areas that are characterized by very distinct heterogeneous patterns of various natural and man-made materials with different bidirectional properties. In order to correct spectrally different surface types in urban areas individually, their bidirectional behavior was analyzed in the present work.

The complex surface structure of urban areas also disturbs the image geometry. Elevated image objects are shifted and the surface behind such an object is hence obscured, causing a loss of surface information. At the same time, facades of these objects are visible and influence image statistics to a considerable extent, being either very bright or very dark.

2. DATA

2.1 HyMap data of central Berlin

Two airborne datasets of central Berlin were acquired on July 30 2003 at almost perpendicular flight directions. Subsets of the overlapping area of the two datasets have been analyzed in the present work. The first, Hym-01, was flown almost directly north with a heading of 12 degrees, as shown in figure 1. The direction of Hym-02 was west to east at 78 degrees. Both scans were performed within less than ten minutes, the sun's azimuth was about 148 degrees, its elevation about 56 degrees. The flight path of Hym-02 was almost perpendicular to the sun-target-observer plane, where bidirectional effects at large view-angles are most dominant. Thus, the resulting brightness gradient can be analyzed very well in Hym-02 using Hym-01 as a reference.

The object shift exists in both images, increasing with growing distance to nadir, but differing in the direction of the shift.
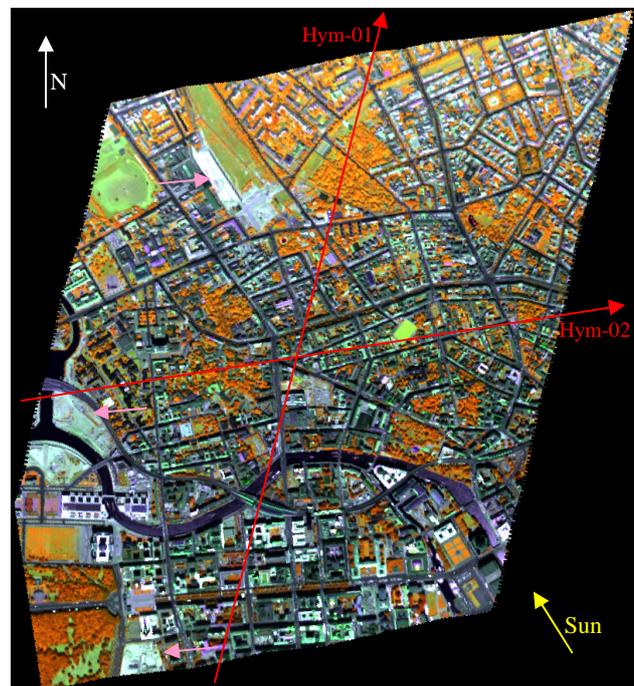
Figure 1. Hym-02 data from central Berlin, July 30 2003; R - Band 27; G - Band 81, B - Band 16. For Details see text.

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2.2 Preprocessing of HyMap data

Previous to further analysis, the images were corrected for atmospheric effects using the ENVI 4.0 atmospheric correction module FLAASH (Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes) and georectified with the software PARGE (PARametric GEocoding) described by Schläpfer (2002). For matters of comparability both images were resampled to an identical grid at 3.5 m resolution. Only gaps in the mapping array were interpolated to maintain original spectral information. Bands with insufficient signal-to-noise ratio were deleted and 116 bands remained in the data set. The atmospheric correction was validated with field spectra, the georectification with GPS measurements and airborne ortho-images.

2.3 Pre-classification of HyMap data

The surface type specific description of bidirectional effects requires a classification that produces good results for both images and can be performed without great influence of bidirectionality. It was hence decided to use a combination of a decision tree and a spectral angle mapping. Thresholds were set in a way to derive spectrally pure classes, accepting that many presumably mixed pixels were not classified.

Five classes were used for the detailed analysis of bidirectional effects: dense vegetation, sparse vegetation, roofs, tarmac, and bright soils. All pixels with a reflectance exceeding 65 percent in one or more bands were masked previous to the classification and considered being 'specular reflectors'. These saturated pixels result from directly reflecting metal or glass roofs. This phenomenon depends on the roofs' inclination rather than the view-angle and shall be interpreted independently.

3. BIDIRECTIONAL EFFECTS

3.1 Across-track illumination gradient

Bidirectional effects are very dominant on vegetated surfaces and have been described by several authors (e.g. Kimes 1983). Figure 2 shows the brightness difference of two spectra from densely vegetated areas in Hym-02; spectrum (a) in the very North, spectrum (b) in the South. The sensor's view-angle for the pixel belonging to spectrum (a) was 29.8 degrees, spectrum (b) was acquired at -23.0 degrees (the sensor's viewing
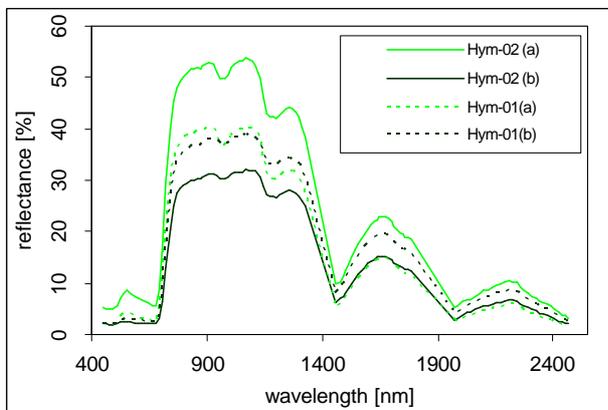
direction towards the sun is indicated by negative angles). In Hym-01 these pixels are located almost in nadir position (1.5 and 6.4 degrees) and the two corresponding spectra are shown for comparison. It is obvious, that vegetated pixels in the northern part of the image appear much brighter in Hym-02 than in Hym-01, while pixels from the south of Hym-02 are much darker than in Hym-01. This shows the across-track brightness gradient when the sensor is flown perpendicular to the sun-target-observer plane.

In general, this gradient is described as a quadratic function with a minimum that is shifted slightly off-nadir towards the sun (Kimes, 1983, Kennedy et al, 1997). In figure 3, the average reflectance of all pixels and bands of Hym-02 and Hym-01 is displayed. Both times the pixels have been sorted by the view-angles of Hym-02 in 5-degree-intervals. While the average reflectances of intervals between -10 and 0 degrees are almost identical, pixels at positive view-angles are brighter in Hym-02 and the difference to the pixels from Hym-01, which function as a reference, increases with the view angle. For large negative angles, pixels in Hym-02 are only slightly brighter.
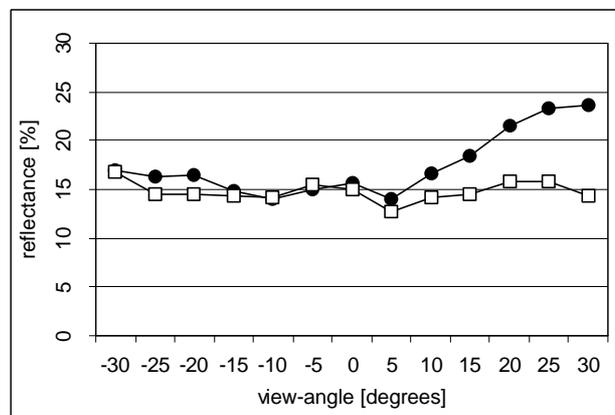
Figure 3. Brightness gradient of Hym-02 (•) and Hym-01 (□) sorted by view-angles of Hym-02. Average of all bands.

An analysis of the classes' overall standard deviation in comparison to the average of the standard deviations within the angular intervals underlines the brightness gradient in Hym-02 and shows that such a similar gradient exists also within each of the spectral classes (compare Beisl, 2001). For Hym-01 both values are comparable for all classes, but the average standard deviation within the angular intervals of Hym-02 – particularly considering vegetation – is significantly smaller than the overall value. Thus, the increased variation can be explained by the view-angle. As can be seen, this effect is less obvious for the classes 'roofs' and 'tarmac' that were classified with the brightness independent spectral angle mapper.

	Hym-02		Hym-01	
	sd	avg sd ang	sd	avg sd ang
dense veget.	6.16	4.68	4.88	4.86
sparse veget.	7.98	6.87	7.09	6.89
roofs	7.27	6.97	6.31	6.21
tarmac	5.46	5.23	4.90	4.75

Table 1. Overall standard deviation and average value of the standard deviations within intervals of Hym-02 view-angles for four classes in Hym-02 and Hym-01.

Figure 2. Vegetation spectra from Hym-02 compared to spectra from the same pixels in Hym-01.
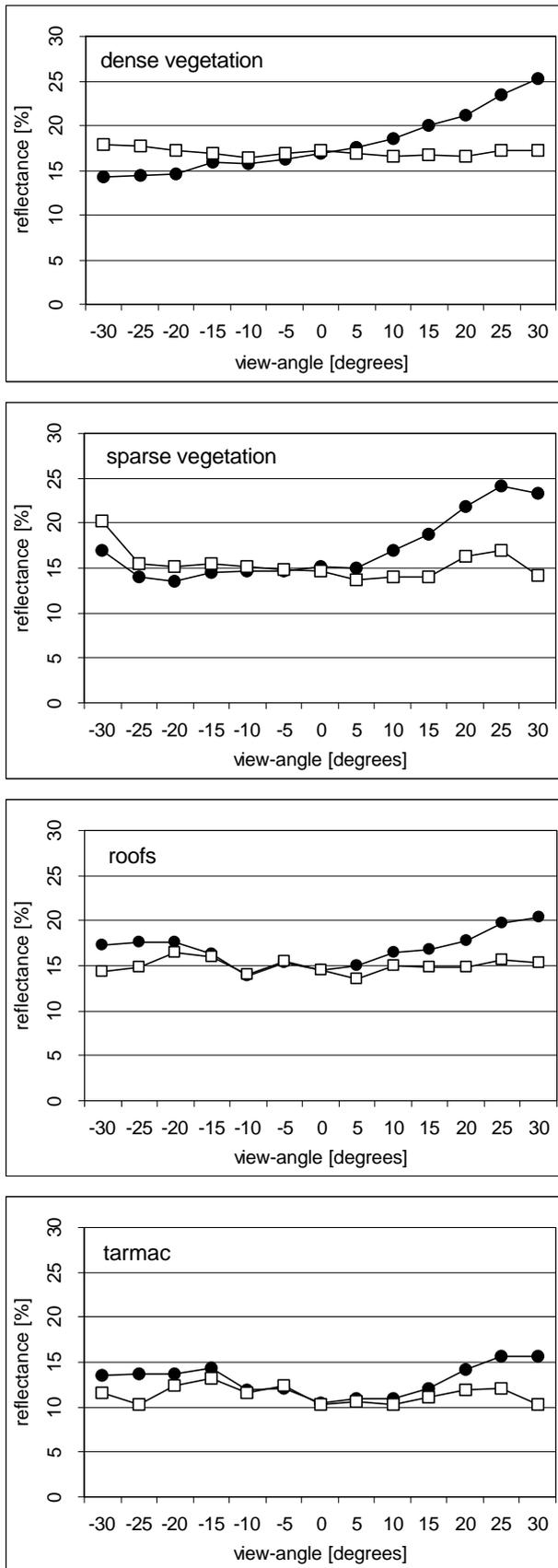
Figure 4. Brightness gradients of Hym-02 (•) and Hym-01 (□) for four classes. Average of all bands.

The brightness gradients of four spectral classes are displayed in figure 4. Again, the brightness at low negative angles is similar for Hym-01 and Hym-02, but differences between the gradients of different classes in terms of shape and intensity can be observed, especially at extreme view-angles.

Densely vegetated areas show an almost linear gradient of increasing brightness with increasing view angle in Hym-02; the values of Hym-01 are almost constant. The gradient of the class 'sparse vegetation' gets closer to the shape of a quadratic function. The values in Hym-01 lead to the conclusion, though, that the brightness increase towards great angles is not induced by the view-angles, only, but might be caused by bright areas that exist in both images.

The ‚bright soil'-class was not equally represented in all angular intervals and was, hence, discarded. Almost all pixels of this class can be found at three construction areas in the western half of the area, as indicated by green arrows in figure 1.

The gradients of the two other classes are more irregular in both images. This might be explained by the general heterogeneity within the classes and the smaller number of pixels assigned to the classes. Both man-made surfaces in Hym-02 appear brighter at negative view-angles than in Hym-02, thus describing more a quadratic function and differing from the linear shape of the vegetated areas' gradients.

In order to validate the gradients in figure 4, where all bands have been averaged, individual bands of the four classes were analyzed: gradients showed similar shapes, which underlines the need of surface type specific analysis, but have different intensities. Especially for densely vegetated areas intensity differed according to the characteristics of vegetation spectra.

3.2   Specular reflectors

The phenomenon of specular reflectors, e.g. metal or glass roofs, has already been mentioned earlier. It denotes an extreme in terms of bidirectionality and complicates the fit of correction functions. Although the direct reflectance of pixels depends more on the surface's inclination than on the position in the image, there is still some relation to the view-angle: the probability of the sun light being directly reflected into the sensor is highest for pixels at very low view-angles. The number of pixels classified as specular reflectors in Hym-02 is up to ten times higher in these angular intervals. The effect and the difference between Hym-02 and Hym-01 is displayed in figure 5 (c) and (d).

Although causing problems in terms of bidirectional effects, the pixels can easily be handled for further qualitative analyses. The maximum reflectance of the majority of the affected pixels is far greater than 65 percent, often exceeding 100 percent, and the pixels can easily be identified and assigned to classes like 'buildings' or 'impervious'.

4.   EFFECT OF ELEVATED OBJECTS

4.1   Object shift

As a function of object height and view-angle, objects are shifted away from the nadir line to the same extent in both images. This shift occurs in almost perpendicular directions, due to the also almost perpendicular flight paths. This way, the

same shifted objects, usually buildings, obscure different areas in the two images and two different sides of the objects become visible in the image. The effect can certainly be utilized for stereoscopic analysis, but causes problems for other image processing steps, e.g. image segmentations.

4.2 Influence on image statistics

Given the sun's azimuth at 148 degrees and its elevation at 56 degrees, the object shift not only influences image geometry but also image statistics. Depending on the object's position either shaded or illuminated pixels are obscured. This effect already influences the spectral properties of the image to a significant extent. The fact that obscured pixels are replaced by pixels with the spectral information of the object's opposite facade increases this effect by far: dark, shaded pixels are replaced by a brightly illuminated facade, and vice versa.

Figure 5 shows two areas in Hym-01 and Hym-02. (a) and (b) are located in the north-western area of the images at view-angles of 11.9 and 26.5 degrees in Hym-01 and Hym-02, respectively. Looking from East at a medium angle onto the buildings in (a) the sensor catches sight of only a few facade pixels and some shaded pixels north-west of the buildings. Pixels in (b) are scanned at 26.5 degrees from South and hence completely illuminated facades cover more area than roofs and shaded areas behind the buildings are completely hidden. (c) and (d) demonstrate the object shift of a larger building: in (d) many more shaded pixels can be seen, while a street south of the building is completely obscured.
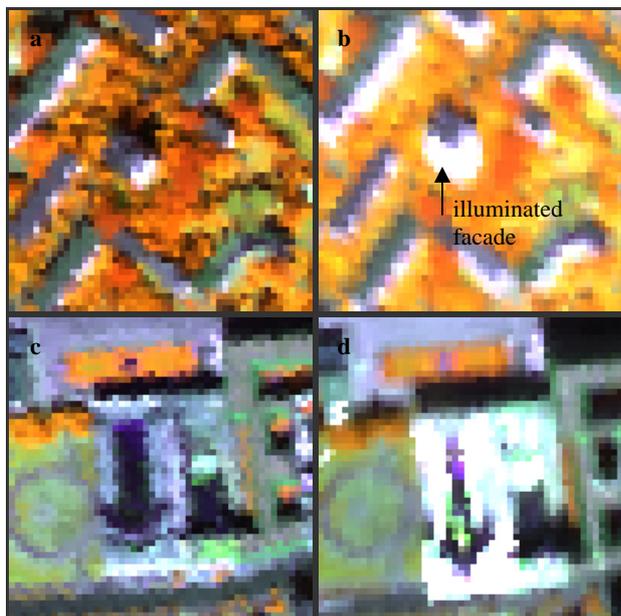
Figure 5. Shifted objects: (a) Hym-01, view-angle 11.9 degrees; (b) Hym-02, 26.5; (c) Hym-01, 12.3; (d) Hym-02, 25.8. (R - Band 27; G - Band 81, B - Band 16)

5. SUMMARY AND CONCLUSIONS

The existence and the effects of the across-track brightness gradient were demonstrated and described. The bidirectional behavior of different surface types and thus their influence on the brightness gradient were analyzed in detail. Results lead to the conclusion that a surface type specific correction of image illumination is needed and should not be performed using an overall gradient. The intensity of the brightness difference demonstrates that further quantitative and qualitative analyses should not be performed without a previous correction of the effect.

The contrary behavior of vegetated and man-made surfaces at low view-angles should be further investigated using the complete datasets, not subsets only. This way, the statistical robustness of the gradients of smaller and less well distributed classes is expected to increase; gradients will be less dependent on local phenomena and a correction using functions that are fit to these surface type specific gradients is promising.

A correction of the effects induced by the object shift can hardly be performed. Given the information of a high precision digital surface model, e.g. derived based on laser scanning, roofs might be moved to their actual position, eliminating the pixels currently showing the facades. But this process is complicated taking into account the resolution of 3.5 meters and the number of mixed pixels. In addition, resulting gaps must be filled with information that usually does not exist. Although the correction of this effect seems not useful at this point, the phenomenon itself should certainly be taken into account during subsequent processing. Especially the validity of classification schemes has to be carefully explored at extreme view-angles, because of the high number of pixels being influenced by the effect.

Based on the findings of the present investigations a sophisticated correction of the bidirectional effects will be performed. This way, data will be prepared for a thorough qualitative and quantitative analysis with regard to impervious surfaces and urban vegetation.

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