

# ANALYSIS OF THE SPECTRAL VARIABILITY OF URBAN MATERIALS FOR CLASSIFICATION. A CASE STUDY OVER TOULOUSE (FRANCE).

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## ABSTRACT:

The automatic classification of urban materials from airborne and spatial acquisitions remains difficult today because of two main reasons: the spatial resolution of the images and the need for pre-processing algorithms to extract ground surface intrinsic properties. This work examines the feasibility of using 8 spectral information distributed in the visible and the near-infrared spectral regions (0.4 - 1  $\mu\text{m}$ ), acquired at a 20 cm spatial resolution, for recognizing the urban materials. The motivation for this study is the development of very high spatial resolution sensors which has introduced a promising capability for the study of urban areas. In this study, an experiment campaign took place in Toulouse. The airborne measurements were carried out using 8 cameras associated with 8 narrow filters (30 nm). Ground spectral measurements of Toulouse's urban materials were performed within the configuration of the airborne acquisitions. These measurements allow us to determine and quantify three types of reflectance spatial variability. The results show that urban materials have low reflectances with no significant spectral features and are then difficult to discriminate. To determine which material classes could be discriminate over the 8 spectral bands of the airborne acquisitions, a statistical analysis was performed on the ground measurements. This analysis highlights that 5 material classes could be discriminated from good quality measurements.

## 1. INTRODUCTION

The advent of high spatial and spectral resolutions sensors enables the study of urban environment with new precision level. Urban area architectures have a very specific man-made structure that may introduce complex phenomena. Indeed, in the visible and near infrared, shadows and environment effects (like scattering of the light on the walls) disrupt the radiance incoming the sensor (Miesch, 2004). To be able to discriminate urban materials, preprocessings are thus required to extract ground surface intrinsic properties from radiance measurements. For many years detailed studies have been carried out developing automatic classification algorithms using airborne or spatial data. Typical urban areas include a wide range of roofs, roads, pavements and squares. Due to the limited spatial and spectral resolutions of the sensors, algorithms were impeded by the abundance of spectrally mixed pixels (Small, 2003). Only broad classes such as urban area or vegetation could be discriminated. Several recent studies have focused on the spectral properties of urban materials from ground measurements (Ben-Dor, 2001; Herold, 2004). They analysed the spectral signatures of urban materials and discussed the relative importance of spectral regions for the classification of urban areas.

The scope of this work is a part of a study which aims to determine the spectral ground reflectance of urban materials from high resolution acquisitions. An experimental validation campaign of this model took place in April 2004. It was composed of airborne acquisitions in 8 narrow filters at a 20 cm resolution in the visible and near-infrared (PELICAN image sensors) and ground truth measurements in Toulouse within the same spatial resolution. The goal of the ground measurements

was to obtain information in three domains: a list of the main materials present in the city, their spectral reflectance properties and their spatial variability.

The investigation presented analyses a part of these validation measurements and is aimed at evaluating the feasibility of discriminating urban materials from the PELICAN configuration images. After having described the airborne configuration, this paper analyses the spectral variability observed for urban materials from ground measurements. A statistical analysis is performed with the 8 spectral bands reflectance values averaged from the ground measurements.

## 2. EXPERIMENT DESCRIPTION

### 2.1 PELICAN airborne acquisitions

The airborne measurements were performed using two high spatial resolution systems (PELICAN) composed of 4 cameras each. The flight altitude was 2250 m and the spatial resolution at ground level 20 cm. The 8 narrow filters associated to the cameras were located in the visible and near infrared from 420 nm to 917 nm. The description of the 8 filters is shown in Table 1. The bands are well distributed in the spectral domain, avoiding the main absorption molecular bands ( $\text{O}_2$ ,  $\text{O}_3$  and  $\text{H}_2\text{O}$ ) except the last one. Indeed, the two last bands in the infrared are devoted to the water vapour content retrieval: the first one located in an atmospheric window, the other centred on a water vapour absorption band.

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Centre wavelength (nm)	Width (nm)
435	30
485	30
550	30
670	30
740	30
870	30
907	20

Table 1: Description of the 8 filters.

The airborne acquisitions took place in April 2004 during two sunny days. Figure 1 shows samples extracted from 8 images obtained during one acquisition over the Toulouse centre.

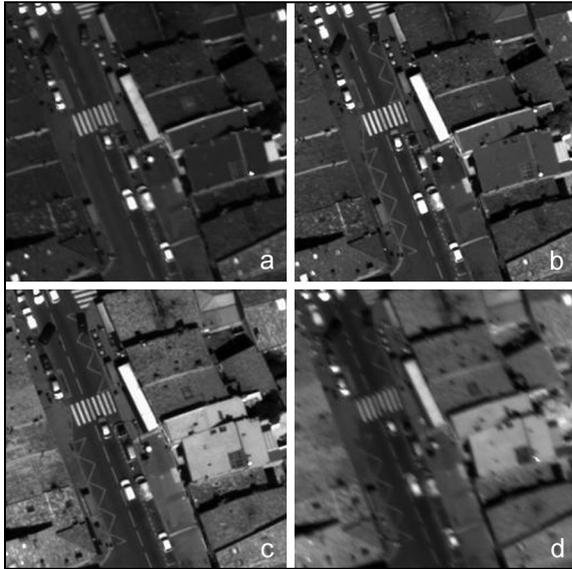


Figure 1: Images of Toulouse centre in four spectral bands among the 8 ones (a: 435 nm, b: 550 nm, c: 670 nm, d: 907 nm).

## 2.2 Ground measurements

These measurements were acquired with an ASD-FR spectrometer ranging from 350 nm to 2500 nm. Reflectance measurements were carried out at a 20 cm resolution, at the nadir in reference with a Spectralon<sup>TM</sup> reference panel.

Such spectral measurements obviously allow to estimate the spectral reflectance of urban materials, but also to quantify their spatial variability. They all took place at solar midday (solar zenith angle of about 35°) in sunny areas in order to reduce as much as possible the irradiance conditions effect. Thus, the major origin of the observed spatial variability is the ground variability itself.

Five material classes were arbitrary defined in this experiment: tar (road), red asphalt and concrete (pavement), granite paving stone (road and square) and slab of granite (square).

## 3. SPECTRAL VARIABILITY ANALYSIS

When we look at buildings or roads in a street, it seems quite simple to discriminate urban materials: they all have specific colours and roughness. However, this discrimination remains more difficult from airborne acquisitions using automatic classification. This is mainly due to illumination conditions and

especially shaded effects, and also directional properties of urban materials (Meister, 2000). Indeed, some urban materials such as tiles reflect different amount of energies depending on their relative orientation towards light sources and observation directions. These phenomena could be nearly corrected by using a radiative transfer algorithm (Richter, 2002; Martinoty, 2004). On the other hand, some misclassifications could come directly from spatial variability of the urban material regardless of irradiance conditions. This section addresses this problem by analysing and quantifying spatial variabilities of typical urban material spectral signatures.

### 3.1 Estimation of the urban materials' variability

Figure 2 shows the averaged spectral reflectance obtained for the main analyzed materials. It can be seen that some spectra like grass are very specific whereas it is difficult to discriminate most materials which have a very low reflectance ranging from 0.05 to 0.2. Several experiments have been carried out to understand and quantify the reflectance variability of these materials. Three variability types were identified in this study (Table 2): a physical variability which is intrinsic to the material, a contextual variability depending on the material use and a class definition variability which is the one observed inside a chosen class.

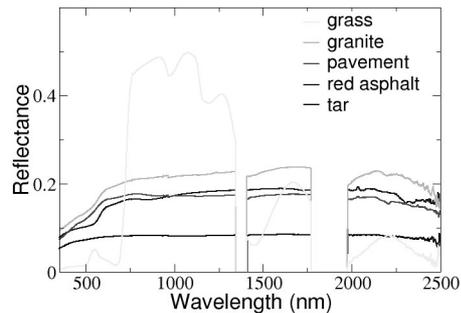


Figure 2: Reflectance of urban ground materials.

The physical variability corresponds to a spatial variation of the reflectance due to the material's roughness and texture. In order to be representative, the measurement spatial resolution (20 cm here) may widely include the scale of the material's roughness otherwise the spectral variability may become important. For instance, this is the case for a square in granite paving stones for which the standard deviation of the measured spectra is 13%. On the contrary, a tar road has a smaller structure, and the standard deviation is less than half lower.

Variability type	Maximum standard deviation
Physical (spatial variation)	13%
Contextual (material use)	30%
Class definition	50%

Table 2: Maximum standard deviation observed for the three variability types.

The spectral reflectance depends also on the material use. Indeed, granite paving stones are located on roads but also on pavements. Cars and people do not degrade or modify ground

the same way. After months or years, the optical properties of the material are affected differently, which produces what is called here the contextual variability. For the case of roads and pavements initially covered by the same material, the measurements show a 30% difference between their respective mean spectra.

Several material classes have been defined depending on the material location. But, there is actually a great diversity of materials in one class. For example, more than five granite types have been found in Toulouse. Each material differs from the others in its colour or its roughness. All the reflectance spectra have the same shape but differ in their reflectance's level, which ranges here between 0.14 and 0.31 at 1000 nm. We called this variability "class definition variability". It is linked to the number and the definition level of the chosen (and thus arbitrary) classes.

### 3.2 Discriminant analysis (DA)

The previous part showed that the maximum standard deviation of spectral measurements could reach 50% for the same material. The goal of the discriminant analysis was to determine if urban materials could be discriminated into predefined classes. The discriminant analysis was built on 250 reflectance measurements acquired during the ground campaign. The set of variables used were the averaged reflectances of the ground measurements in the 8 bands defined previously. Figure 3 shows the two-dimensional scatterplot which plots observations by the two first eigenvectors.

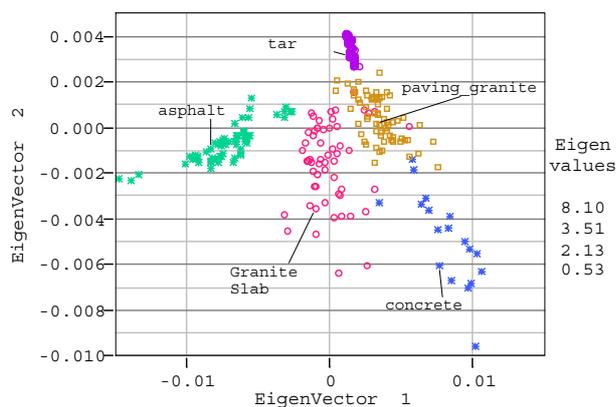


Figure 3: Discriminant analysis of urban materials plotting observations by the two first discriminant functions.

The measurements appear well gathered, class by class. To confirm this observation, discriminant analysis pairs were calculated according to the Rao's V distance (corresponding to a generalized measure of the Mahalanobis distance).

$V_{Rao}$ (dB)	Asphalt	Concrete	Tar	Granite slab	Paving granite
Asphalt	-	35.1	33.9	29.3	31.1
Concrete	35.1	-	36.1	27.1	28.9
Tar	33.9	36.1	-	27.7	29.9
Granite slab	29.3	27.1	27.7	-	26.6
Paving granite	31.1	28.9	29.9	26.6	-

Table 3: DA pairs for each class.

We can see in Table 3 that the Rao's V value, for each couple of classes, is high enough to allow a discrimination of them. Even

granite slab and granite paving stone which are both made in granite could be discriminated at a 20 cm resolution.

## 4. CONCLUSIONS

This work aimed to evaluate the feasibility of discriminating urban materials at 20 cm resolution from 8 spectral bands in the visible and the near-infrared. The analysis carried out from ground measurements highlights that urban materials show an important spectral variability. A statistical approach however confirms that the discrimination is still possible when considering 5 usual urban classes.

The next step of this study will consist in considering reflectance spectra extracted from airborne measurements and corrected from atmospheric and illumination effects. In this case, the classification relevancy will also depend on the used inversion algorithm and the classification result analysis will determine the required correction accuracy.

## 5. REFERENCES

Ben-Dor, E., Levin, N., Saaroni, H., 2001, A spectral based recognition of the urban environment using the visible and near-infrared spectral region (0.4-1.1 m). A case study over Tel-Aviv. *International Journal of Remote Sensing*, 22(11), pp. 2193-2218.

Herold, M., Roberts, D.A., Gardner, M.E., Dennison, P.E., 2004, Spectrometry for urban area remote sensing – Development and analysis of a spectral library from 350 to 2400 nm. *Remote Sensing of Environment*, 91, pp. 304-319.

Martinoty, G., 2003, Materials' BRDF retrieval from multiview digital aerial images. *Geoscience and Remote Sensing Symposium 2003, IGARSS '03, Proceedings. 2003 IEEE International*, 6, pp. 3851-3853.

Meister, G., Rothkirch, A., Spitzer, H., Bienlein, J., 2000, BRDF field studies for remote sensing of urban areas. *Remote Sensing Reviews*, 19, pp. 37-57.

Miesch, C., Briottet, X., Kerr, Y., 2004, Phenomenological analysis of simulated signals observed over shaded areas in an urban scene. *IEEE Transactions on Geoscience and Remote Sensing*, 42(2), pp. 434-442.

Richter, R., Schläpfer, D., 2002, Geo-atmospheric processing of airborne imaging spectrometry data. Part 2: atmospheric / topographic correction. *International Journal of Remote Sensing*, 23(13), pp. 2631-2649.

Small, C., 2003, High spatial resolution spectral mixture analysis of urban reflectance. *Remote Sensing of Environment*, 88, pp. 170-186.

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