Green infrastructure mapping within an urban context using Pleiades HR over Strasbourg

Jérôme Maxant[1], Henri Giraud[1], Stephen Clandillon[1], Colette Meyer[1] and Paul De Fraipont[1]

SERTIT, University of Strasbourg, Illkirch - Graffenstaden, France; sertit@sertit.u-strasbg.fr

Abstract. The objective of this study is to explore the pertinence of mapping urban greenness, and hence all low-lying and tall vegetation within urban and suburban areas using data acquired by the recently launched Pleiades 1A sensor. Of course green areas within out-lying or in-lying rural and/or agricultural areas are taken into account. The target here is to develop services for land planners to provide means with which to observe both in detail and extensively green infrastructure over a given areas be it on public or private lands, to develop an overall view. The request that is crystallizing is the provision of a geo-information layer that can be generated at a reasonable cost, over large areas and still be used for 1:2 000 land planning processes. The land planning specifications stipulates the mapping of low-lying permanent vegetation surfaces including prairies and grass-strips, urban grasslands, scrublands, isolated large trees, and other landscape characteristics such as hedges, woodlands and forests. The mapping of these features requires their distinction from croplands and permanent urban mineral surfaces and other more specific features such as paths. Furthermore, the work needs to take into context the roads and hydrology networks.To meet this demand SERTIT is proposing a remote sensing and GIS solution using imagery acquired by the recent sensor Pleiades 1A at 50cm. Supported by the CNES, SERTIT received a good coverage of the Urban Community of Strasbourg (CUS) and its environs and embarked on an ambitious and time-constrained initial green infrastructure mapping of nearly 400km2. Firstly, SERTIT insured a strict observance of geometrical specifications. Then, after radiometric calibration pixel based and object-orientated methods were prototyped incorporating image bands, neo-channels and textural indices to produce the vegetation layers. This article will outline aspects of the chosen method and initial results showing the advantages of Pleiades in the precise mapping of vegetation in complex urban environments.

Keywords. Green infrastructure, corridors, biodiversity, urban vegetation, Pleiades satellite, detailed urban planning mapping

1. Introduction

Since 2010 and the National Commitment to the Environment (Grenelle 2 Law) decided by France, policies aimed at curbing wild and domestic biodiversity losses and at creating a green and blue infrastructure must be taken throughout France. When considering the Communauté Urbaine de Strasbourg (CUS – Strasbourg Urban Community), a Plan Local d'Urbanisme (Local Urban Plan) taking into account biodiversity and ecological continuity must be established in order to ensure harmonious land planning throughout its territory.

The CUS already has a green and blue infrastructure mapping at 1 / 15 000 covering its area. The objective of this work is to refine the mapping and to optimize the differentiation of green and blue constituent features. A more precise knowledge of the agglomerations vegetation is considered really necessary as what the CUS had up until now didn't enable the analysis of continuities and the classification of connections between the principal biodiversity reservoirs, components of the green and blue infrastructure.

The request that is crystallizing is the provision of green and blue infrastructure geo-information that can be generated at a reasonable cost, over large areas and be used for 1:2 000 land planning processes. The land planners require the mapping of low-lying permanent vegetation surfaces including prairies and grass-strips, urban grasslands, gardens, and scrublands, plus tall vegetation such as isolated large trees, hedges, woodlands and forests including riparian forests. The mapping of these features requires their distinction from water surfaces, croplands and permanent urban mineral surfaces. Urban planners also wish to have man-made and natural networks such as roads and hydrological networks taken into account as these can act as barriers within biotopes.

To meet this demand SERTIT is proposing a remote sensing and GIS solution using imagery acquired by the recent sensor Pleiades 1A at 50cm. Supported by the CNES, SERTIT received a good coverage of the Urban Community of Strasbourg (CUS) and its environs and embarked on an ambitious and time-constrained initial green infrastructure mapping of nearly 400km2. This article and the associated poster will outline aspects of the chosen method and results showing the advantages of Pleiades in the precise mapping of vegetation in complex urban environments.

2. Method

As with most remote sensing/GIS based projects, R&D or not, SERTIT worked in partnership with the user and image provider to help establish a reference database. Then, the usual geometric, thematic processing, post-classification and validation phases were subsequently tackled with the main objective of providing geo-information on vegetation cover at a 1: 2 000 scale to the user, the Communauté Urbaine de Strasbourg (CUS – Strasbourg Urban Community), within 6 weeks. This included two phases: a test site phase and upon agreement a generalization of the method. For simplicity the final method will be illustrated here.

The Pléiades 1A data used for this work were acquired during Spring and Summer 2012, within the sensor's commissioning phase and were received in ortho-ready bundles – separate multispectral and panchromatic data. These data were provided by the French Space Agency (CNES) during Pléiades thematic commissioning phase. To insure geometric compatibility with the CUS' GIS they made a large and precise dataset available: a 16cm resolution ortho-photo coverage (2010); building polygons and commune boundaries (BD Topo 2 000 CUS) ; built-up areas, urban sectors, green spaces (BD Carto 10 000 CUS) ; and their own road and waterway networks.

In image areas outside the CUS a national geographical reference database was used, the French national référentiel à grande échelle otherwise known as the IGN RGE® created and updated by the IGN, to insure a precise geometric fit. Most notably this includes the BD Ortho®, a 50cm orthophoto and the BD ALTI®, a nationwide DEM. This was supplemented by the Ministry of Agriculture's Registre Parcellaire Graphique - a census of farmer crop declarations per crop parcel to provide outside landuse information.

2.1. Geometric processing

Here the challenge was to insure geometric conformity to user specifications – maximum of a 1m displacement with respect to CUS reference data. A two stage geometric correction was applied to the Pléiades data, with each stage being validated, following Dr. Philip Cheng's [1] test advice after having used the Pléiades demonstration products, put on-line by Astrium Geo-Information Services (AGIS). Firstly, a RFM (Rational Function Method) ortho-rectification based on the RPCs (Rational Polynomial Coefficients) supplied with the data was applied using reference points. Following on our own tests a polynomial order of zero was employed. Then, secondly, a 1st order polynomial adjustment is applied to reduce further residual error. Given the required precision all control points were taken on the ground from the smallest possible, permanent features. This is advisable given the very different image acquisition parameters encountered from this agile satellite (Table 1). All data were sampled to 0.50m to avoid varying pixel sizes.

Table 1. – Selection of Pléiades image acquisition angles

Date	(Along Track)	(Across Track)	Overall Incidence Angle
01/04/2012	-0.74529203	30.24018734	30.24639293
14/08/2012	-2.03400462	13.76736549	13.905682
09/09/2012 (E)	-28.69403145	19.99851949	33.05609209
09/09/2012 (W)	29.30927479	7.06033849	29.89402462
21/09/2012	-4.51841171	2.81837687	5.3191822

2.2. Radiometric processing

To obtain a more homogeneous, normalised database radiometric correction procedures are implemented. The procedure is divided into two steps: a process to calculate Top Of Atmosphere reflectance values and a pansharpening procedure. To obtain the Top Of Atmosphere reflectance values the digital numbers of the ortho-rectified images were transformed to exo-atmospheric reflectance values. The equation below integrates both the transformation to spectral radiances (L = (DN – Offset) / K) and the transformation to Top Of Atmosphere reflectance values. Here and generally speaking Offset = 0 in AGIS sourced data [2], [3].

$$\rho = \frac{\pi \times d^2 \times DN}{E_{sun} \times \cos(\theta s) \times K}$$

where

- ρ, band reflectance for the wavelength interval under consideration [λ_1, λ_2],
- *DN*, measure captured by the sensor in the wavelength interval under consideration [λ_1, λ_2],
- *K*, gain for the band [λ_1, λ_2],
- θs, solar zenithal angle. (complementary to solar elevation angle θ_E),
- E_{sun} , solar constant equivalent to the solar energy incident on one square metre outside of the Earth's atmosphere for a given spectral band [λ_1, λ_2],
- *d*, Earth-Sun distance expressed in astronomical units.

The pan-sharpening procedure is chosen to best integrate the higher resolution texture of the panchromatic image with the multispectral image's lower resolution spectral information. Following much internal and external testing the PCI Pansharp method was chosen as the most appropriate [4]. The resulting high spatial resolution image conserves spectral fidelity plus the detail and texture of the panchromatic image enabling better geo-information extraction and interpretation of imaged areas. The pan-sharpened image was used in image processing thematic information extraction procedures not just photo-interpretation.

2.3. Thematic mapping

Firstly, a pixel based method is foreseen for mapping bush/tree-like vegetation. This approach has several disadvantages though. From experience, forest mapping at sub-metric resolutions is complicated because of shadowed and over-exposed areas of trees plus the usual spectral overlap with certain low-lying vegetation surfaces (Figure 1). The human eye easily distinguishes, though, these surfaces and hence texture and contextual information are required.

Figure 1. Difficulty in discriminating between low-lying (yellow) and high (red) vegetation signatures. A spectral overlap is seen between low-lying (bright green) and high vegetation (dark green) areas.

Whereas the spectral characteristics are quite similar there must be a fairly clear textural/contextual difference, high vegetation is less homogeneous than low-lying vegetation. Hence, a texture index is elaborated to test whether the vegetation types can be better separated. The resulting index is calculated for vegetated, relatively high textured and green areas (Figure 2) within an adapted window.

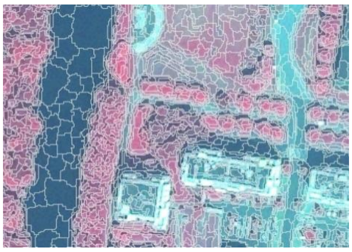
Figure 2. An example of the texture index used to map high vegetation – The riparian woodlands are highlighted here – standard Pléiades NIR colour composite on left, texture index on right.

This index greatly reduces overlap with low-lying vegetated areas but errors do persist particularly within unused land (agricultural or otherwise) and within certain textured fields (Figure). This can be overcome of course using a multi-temporal dataset.

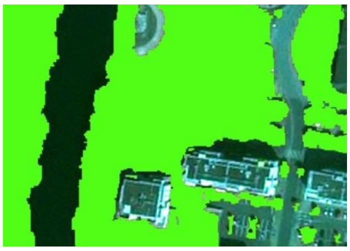
Figure 3. Texture index highlighting a copse, agricultural paths and tractor paths in fields (yellow circles) – standard Pléiades NIR colour composite on left, texture index on right.

Given the spectral and textural complications it was decided to test an object oriented approach to incorporate contextual information into the procedure. After much testing, using eCognition, a two layered segmentation was established, one general the other more detailed and a classification process established to separate as much as possible high from low-lying vegetated surfaces. The resulting hierarchical classification first extracts vegetation surfaces and then the high and low-lying vegetation (Figure).

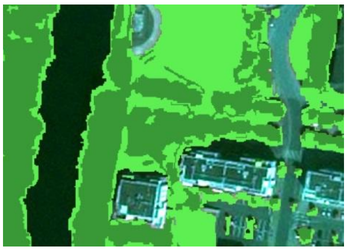
14/08/2012 Pléiades Image



Detailed segmentation layer



Vegetation class



Result of object oriented high / low-lying vegetation classification

Figure 4. Illustration of object oriented classification procedure

The high vegetation class covers nearly all the trees and bushes but nevertheless the class needs further generalization and re-touching. The post-classification processing involves infilling small gaps in the high vegetation class linked to shadowing very small, slightly mineral surfaces that the objects wrongly included and on-street trees using combined GIS and spectral properties. The class was then validated by photo-interpretation: removing dark low-lying vegetation at shadow edges; very bright, low textured trees and scrub in unused land parcels.

In rural areas a crop-type classification was requested discriminating between winter and spring crops and this on a crop-parcel basis. Hence, after crop classification land parcels are attributed on a majority basis to these classes (Figure 5).

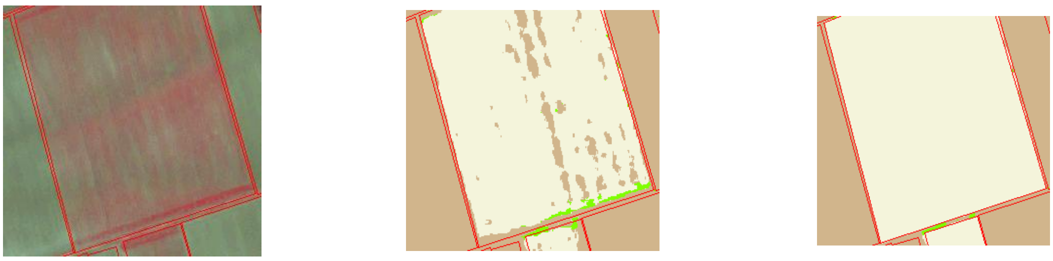


Figure 1. Example of crop classification homogenisation using the 2012 crop parcels (RPG): Crop-parcels overlain on the 01/04/2012 Pléiades image (left), the initial crop classification (centre) and majority crop allocation to parcels

3. Results and Validation

An internal geometric validation at SERTIT and an external validation by CUS services confirmed that the Pléiades imagery were well within the 1m RMS error of the CUS's ortho-photo-plan (16cm) even at the worst points and therefore met the necessary geometric specifications (table 2).

Within the thematic validation exercise a total of 250 points are distributed on a random but proportionate basis between the 5 main classes: winter crops, spring crops, low-lying vegetation, high vegetation and mineral surfaces (water included). The initial figure is derived from Congalton and Green's suggestion to have 50 validation points per class and a proportionate distribution is chosen as more representative [5]. The ground information for comparison is sourced through photo-interpretation of the CUS' ortho-photo-plan. The confusion matrix indicates 234 correct points out of 250 which represents close to 94% conformity.

Table 2. A confusion matrix of Pléiades derived classification (lines) versus reference data (columns)

	Mineral surfaces	High vegetation	Low-lying vegetation	Winter crops	Spring crops
Mineral surfaces	76	1	1	0	0
High vegetation	1	56	6	0	0
Low-lying vegetation	0	2	34	1	1
Winter crops	0	0	0	10	0
Spring crops	1	0	1	1	58

The Kappa analysis and hence coefficient (KHAT) which measures the degree of correlation of these results, at 0.83, indicates a high degree of correlation between the photo-interpreted 'ground' information and the Pléiades derived classification (Figure 6). The statistical analysis procedures are derived from a reference book [5].

Figure 6. Classification of the CUS area with zoom to show detail

4. Conclusions

In order to satisfy the environmental requirements incorporated into law in 2010 and the National Commitment to the Environment (Grenelle 2 Law), the CUS must establish a Plan Local d'Urbanisme (Local Urban Plan) which treats biodiversity and ecological continuity questions to ensure harmonious land planning throughout its territory. To complete its green and blue infrastructure mapping at 1 / 15 000 and to obtain a more precise classification (which could be used at 1 / 2 000) in order to identify continuities and the hierarchy of connections between the main biodiversity reservoirs, the CUS has called upon satellite resources.

In this case the resources are Pléiades data from April, August and September 2012 with a 0.50m pan-sharpened pixel size. The geometric correction successfully met the 1m maximum error requested by the CUS and the data were normalized for TOA reflectance before the thematic mapping to classify most notably vegetation surfaces. To aide in this endeavor the CUS provided a comprehensive urban data base and other layers were sourced.

The most complicated task was to separate high from low-lying vegetation. The same approach was applied in rural and urban areas: an object based classification to benefit from the spectral, textural and contextual characteristics of features in Pléiades data following by GIS and pixel based post-classification processing.

To insure compliance with a specified Urban Ecology Service demand concerning a thematic accuracy of above 90% the classification was tested using 250 randomly but proportionately distributed points. The result indicates an overall accuracy of close to 94%. Furthermore and with respect to high vegetation, the highlighting of riparian forest plus the sub-division according to size and form into forests, woods, copses and hedges, according to agreed-upon criteria was carried out. In the same light, grass strips which are important features of green infrastructure were distinguished. The aforementioned work took into account road and hydrological networks.

Furthermore, the integration of 3D information into mapping and modeling green infrastructure will be investigated. Finally, and accounting for the wealth of sensors available, multi-scale or resolution data will be studied with respect to scales of work and temporal frequencies.

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