EVALUATION OF THE POTENTIAL OF PLEIADES SYSTEM FOR 3D CITY MODELS PRODUCTION : BUILDING, VEGETATION AND DTM EXTRACTION

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ABSTRACT:

The Pleiades system developed by the French space agency CNES shall be ready for launch in early 2009. It deals with a new generation of high resolution optical satellites. The great agility of Pleiades satellites with their motion capability in roll, pitch, and heading, will allow new acquisition modes which are impossible with SPOT series satellites. Indeed, the system will be able to perform three-fold stereoscopic colour images of 20km swath and 70cm resolution. Several experimentations and simulations are being carried out in order to verify the ability of the system to fulfill the technical and operational requirements of the map-making processes.
Last year, a first study has been carried out on 3D city models production on two small areas from simulated images and with a lot of different contexts. Considering the promising results, studies carry on this year, with more different areas and Pleiades simulation images more realistic. Two other topics have been studied : automatic vegetation detection and DTM processing. Concerning building extraction we have used the same production line as last year. Concerning vegetation extraction we tested two methods. The first one is classic : we threshold the Normalized Difference Vegetation Index (NDVI). The second method is more elaborated : it deals with an algorithm which studies the value of texture features and transforms colour spaces for segmentation and classification. For the DTM calculation we have used a method based on elastic grid algorithm. Finally we have integrated all these different necessary primitives (buildings, vegetation and DTM) to produce a complete 3D model on new datatests areas.

1. INTRODUCTION

1.1 Context and objectives

The Pleiades system developed by the French space agency CNES shall be ready for launch in early 2009. It deals with a new generation of high resolution optical satellites. The great agility of Pleiades satellites with their motion capability in roll, pitch, and heading, will allow new acquisition modes which are impossible with SPOT series satellites. Indeed, the system will be able to perform three-fold stereoscopic colour images of 20km swath and 70cm resolution. Several experimentations and simulations are being carried out in order to verify the ability of the system to fulfill the technical and operational requirements of the map-making processes.

Last year, a first study has been carried out on 3D city models production on two small areas from simulated images and with a lot of different contexts. The simulated images were at 50cm and 70cm resolution and production has been made both with and without cadastral maps and tested with stereo or tri stereo, in urban or periurban context. Several conclusions of this work (see (Flamanc and Maillet, 2005)) :
- if there is no cadastral maps, the production time is increased more than 40%.
- level of details (number of facets for 1km^2) and exhaustiveness are improved by the use of a cadastral map.
- the height accuracy is metric.
Considering the promising results, studies carry on this year, with more different areas and Pleiades simulation images more realistic. Two other topics have been studied : automatic vegetation detection and DTM processing.

1.2 Pleiades-HR simulations

Very fine simulations of stereoscpic triplets have been provided by the CNES. These simulations are made with aerial images of the digital frame camera developed by the National Cartographic Institute of France (IGN) (Thom and Souchon, 2001). CNES has used the Modulation Transfer Functions (MTF) and the Signal to Noise Ratio (SNR) of the aerial images to calculate realistic radiometric simulations of images of the future Pleiades-HR satellite. But source images come from a digital frame camera instead of a line scanner system, and there are not geometric simulations. That means the Pleiades-HR simulations used in this paper simulate only the radiometric quality but keep the same conic geometry and the same calibration as the initial aerial images. This has two consequences. On the one hand, these evaluations do not take into account the specific geometry of the future images of Pleiades-HR. But, on the other hand, there are not problems of bundle adjustments between the simulations and the reference images.

1.3 Structure of the article

We first present building reconstruction. We detail some adaptations for its use in this particular context. Then, we will describe vegetation extraction and DTM extraction. Finally, we will present a complete 3D model produced from these three kinds of primitives. We will conclude and present the future work.

2. BUILDING RECONSTRUCTION

The previous work on Pleiades simulation images has shown their ability for 3D city models production (Flamanc and Maillet, 2005). The general principle for production is the same, but we implemented a new algorithm for the building reconstruction. It is derived from (Taillandier and Deriche, 2004) which is a general building reconstruction algorithm. It has been adapted to take into account cadastral limits (or more generally, building outlines). The principle of the algorithm is to propose all of the

possible models from a building outline and then chose the best model according to a criteria of likelyhood to the digital elevation model (DEM) used. Finally, one slope and one height of gutter are estimated for a building.

This adapted algorithm has been evaluated on a dense urban center and it showed its robustness : more than 85% of the reconstructions are acceptable (Durupt and Taillandier, 2006). However, this evaluation has been made with a DEM produced with 25cm resolution images, it is then of a very high quality.

In our particular context, we use 70cm resolution images sampled at 50cm resolution. The correlation DEM produced (Pierrot-Deseilligny and Paparoditis, 2006) is then more smooth than the one produced with 25cm resolution images. That is why we want that the operator can impose constraints : he can identify on the true orthophoto if the building has a saddleback roof or a hip-roof for example. We rely this constraint to the number of triangular facets in the model.

We then have two more steps in comparison with the previous algorithm : firstly, we calculate which sides of the building outline can support a triangular facet. Then, we verify and filter the proposed models whether or not they correspond to the constraint imposed by the operator. There are not as many possible models and the choice with the DEM is easier : we can limitate the number of false reconstructions even with a bad DEM.

Figure 1. Example of a building (true orthophoto and shaded DEM) : there are 2 triangular facets.
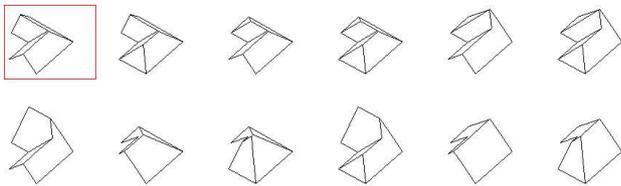
Figure 2. 12 of the 31 possible models without any constraint. The first model is the chosen solution.
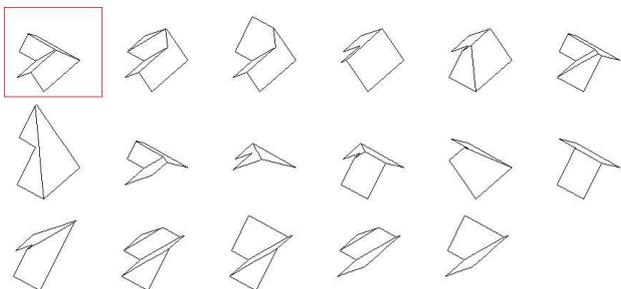
Figure 3. The 17 possible models with the constraint "no triangular facet". The first model is the chosen solution.

The figures 2, 3, 4, 5 show the results obtained with the possible constraints that the operator can infer. We can notice that without constraint, a generalized model is chosen.

An example of a real production project is shown in section 5.
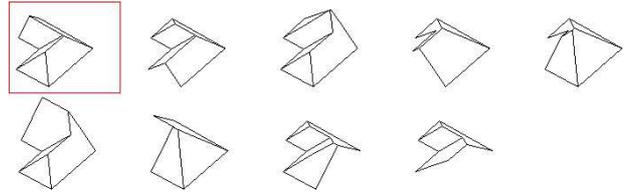
Figure 4. The 9 possible models with the constraint "one triangular facet". The first model is the chosen solution.
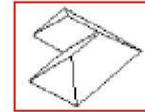
Figure 5. The only possible solution with the constraint "two triangular facets".

3. VEGETATION EXTRACTION

The Pleiades-HR instrument will provide images in four colors : blue, green, red and near infrared. For vegetation extraction, we tested two methods. The first one is very classic and is based on the thresholding of the NDVI. The other method is a supervised classification.

3.1 Normalized Difference Vegetation Index

The Normalized Difference Vegetation Index (NDVI) is computed from the near infrared (NIR) and red bands (R) and is defined by equation 1.

$$NDVI = \frac{NIR - R}{NIR + R} \qquad (1)$$

This method is very fast to implement and provides excellent results, especially on urban center (see figure 6). Its main drawback is that the threshold NDVI value has to be adjusted for every aerial photograph. An other disadvantage is that we can not have any distinction between the sorts of vegetation. In our context, for DTM extraction, we particularly need high vegetation. In rural area, we can not have any difference between fields and forest for example (see figure 7).

3.2 Supervised classification

First of all, terrain classes are defined by the operator. In the present case, the classes were "trees" (or high vegetation), "grass" (or low vegetation), "tiles roofs", "flat cemented roofs", "soil" and "asphalt". A set of polygons is manually defined in a training image for each terrain class.

The classification is performed on an image of which the channels have been computed from the initial image. These derived color channels are selected taking into account the most important classes, allowing to distinguish them. In our case, as we are particularly interested in vegetation classification, NDVI (as defined in equation 1) and TGDVI (Three-band Gradient Difference Vegetation Index, equation 2) were used. TGDVI can be computed from the green (G), red (R), and near infrared (NIR) bands (whose central wavelengths are, respectively, λ_g, λ_r and λ_{nir}, in our case, $\lambda_g = 550nm$, $\lambda_r = 660nm$ and $\lambda_{nir} = 850nm$).
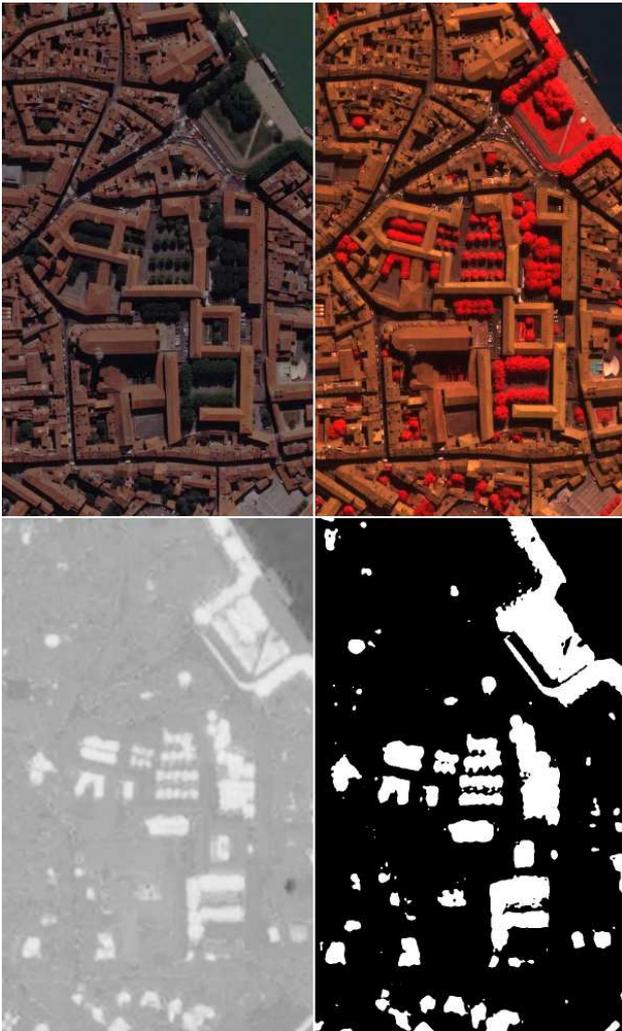
Figure 6. Results on a dense urban center. 1st row : RGB image and in colour infra-red. 2nd row : NDVI image before and after thresholding (in white : vegetation, in black : non vegetation).

Figure 7. Results on a rural area. 1st row : RGB image and in colour infra-red. 2nd row : NDVI image before and after thresholding (in white : vegetation, in black : non vegetation).

$$TGDVI = \min\left\{0, \frac{NIR - R}{\lambda_{nir} - \lambda_r} - \frac{R - G}{\lambda_r - \lambda_g}\right\} \qquad (2)$$

On figure 8, we can see that the "trees" class and the "grass" class are quite dissimilar using these channels.

A per region classification (with a partition of the image in regions obtained after an image segmentation) and a per pixel one have been performed. The classification methods used in both cases are "maximum likelihood" ones (Trias-Sanz and Boldo, 2005). Maximum likelihood classification consists of two steps:
- Firstly, probability models are estimated for each terrain class. A histogram for the derived color channels values of pixels in the different classes is constructed from the training data. The probability models of the different classes are then selected in a set of possible models and their parameters are estimated, using these histograms.
- Secondly, the classification is performed. For each region or for each pixel of the image, the probability of belonging to the different classes is computed, owing to the class probability models previously estimated. The label given to each region or each pixel is finally its most probable class.

The results of these two classifications are shown on figure 9. In both cases, the results are satisfying, with user and producer accuracies upper than 97% for the "trees" and "grass" classes in rural area. We can notice and (it is well known) that the result of a pixel classification provides a black and white noise. On the contrary, region classification provides more regular regions.

4. DIGITAL TERRAIN MODEL EXTRACTION

A Digital Terrain Model (DTM) is derived from the initial Digital Surface Model (DSM) and above-ground (buildings and vegetation) masks. The algorithm used in our work estimates the final reconstructed topographic surface (i.e the DTM) by fitting an elastic surface to a finite sample of observation points (i.e points considered as ground points in the DSM i.e points out of above-ground masks). Mathematically, that comes down to minimize an energy that contains a data term and a regularization term. The main specificity of this algorithm is to reject outliers present in input data (typically above-ground points out of above-ground masks) from calculation : in this way, the final DTM fits the "true" topographic surface for the best. To that purpose, a robust norm, the Tukey norm derived from the robust statistics theory, has been introduced in the data term. More details can be found in (Champion and Boldo, 2006).
The results are very satisfying : displaying both DTM and DSM in the same scale range shows the reconstruction is faithful to reality (see figure 10). Moreover, profiles have been edited in order to assess these results qualitatively. As can be seen on figure 11, the "blobs" that correspond to buildings and vegetation in the DSM are perfectly filtered, which shows the robustness of the method. Moreover, the final DTM clings to points in streets and courtyards and reconstructs all the small undulations of the topographic surface, which shows the accuracy of the method.
Nevertheless, some problems occur locally. In particular, the final DTM is locally and slightly deviated upwards (see figure 12). That happens wherever there is a big aggregation of vegetation which is not present in the vegetation mask (by lack of accuracy). In that case, some above-ground points are taken into account at the beginning of the process, the reconstructed model clings to these points and never reject them so that a small blob is created
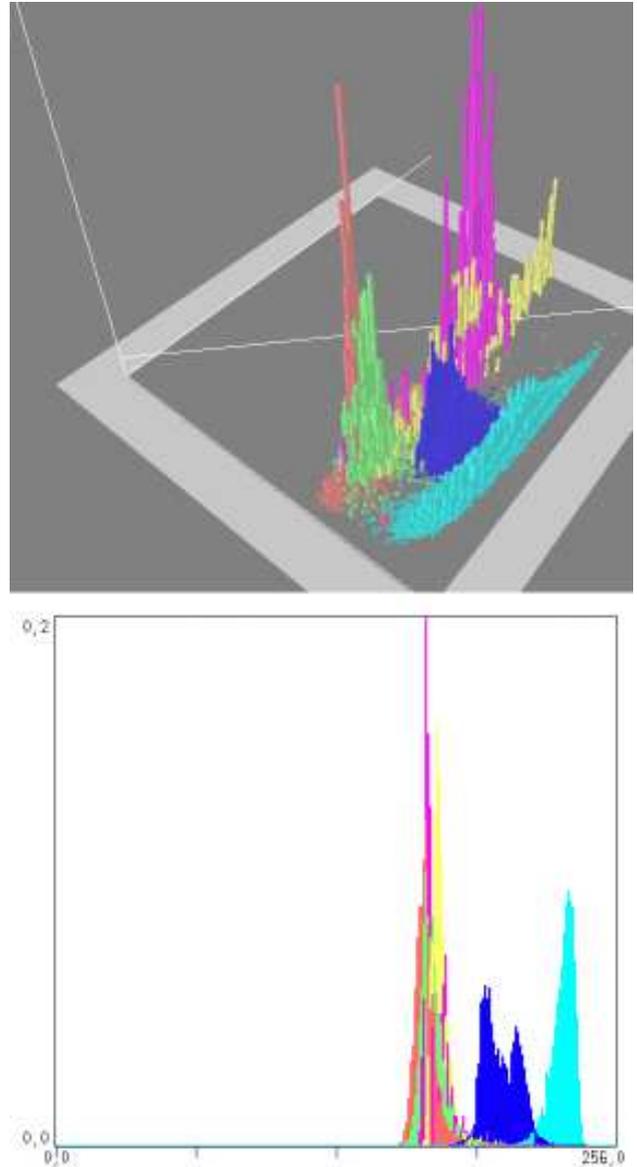
Figure 8. 3D histogramm (X axis = NDVI, Y axis = TGDVI, Z axis = distribution of pixel values) for some classes (in particular, tree class (light blue) and the grass class (dark blue)). On the 2D histogramm (X axis = NDVI, Y axis = distribution of pixel values), we can see that the tree class (light blue) and the grass class (dark blue) are quite distinct.
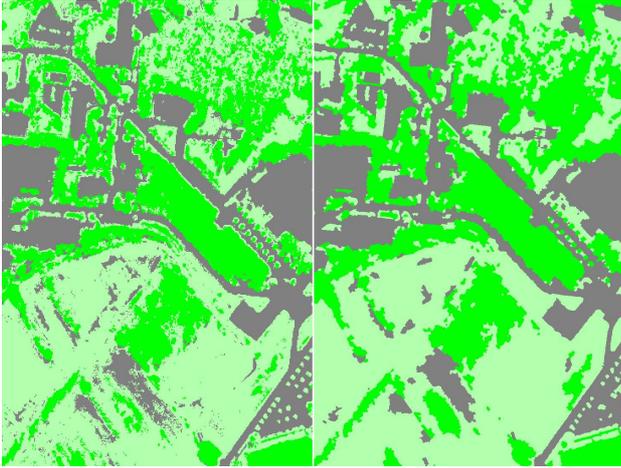
Figure 9. Results of classifications on a rural area : pixel classification (left), region classification (right). Classes represented: high vegetation (light-green), low vegetation (dark-green) and non vegetation (grey).
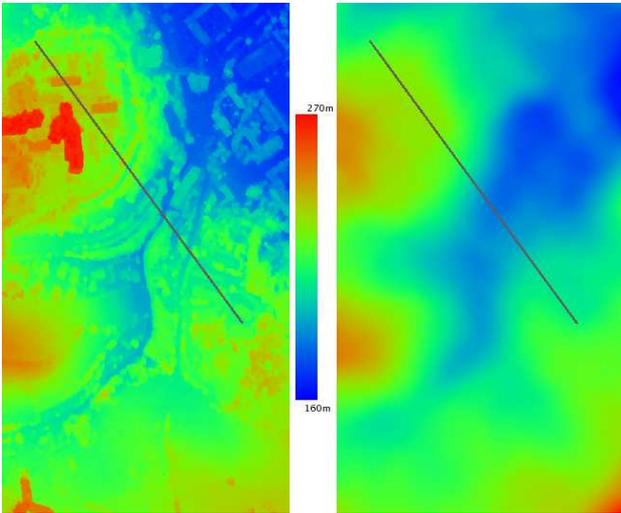
Figure 10. Comparison of the original DEM and the deduced DTM on a hilly area.

in the final DTM. Forthcoming researches are needed to fix the problem (a new and dissymetric norm could be tested in the data term).

5. COMPLETE 3D MODEL

We finally integrate all of these results in a complete model. First, we produce a DTM + high vegetation : in area of high vegetation, altitudes are those of the DEM. Then, we add the 3D building models. Eventually, we drap this complete 3D model with the Pleiades simulation images. Only roofs of the buildings are textured. A view of the result can be seen on figure 13
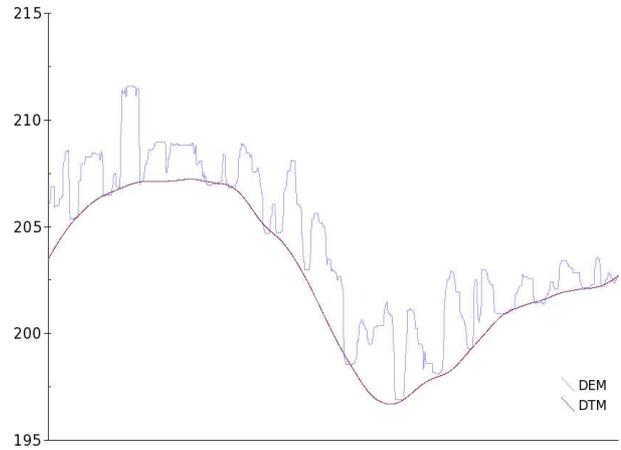
Figure 11. Profiles along the line drawn on figure 10.
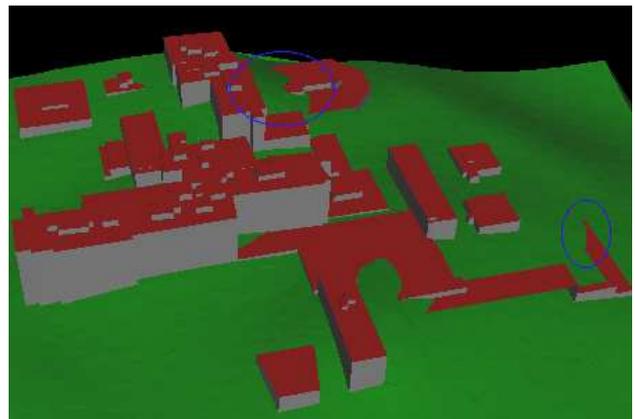
Figure 12. Example of local artefacts : superimposition of the extracted DTM with buildings models (produced according to the method described in section 2.). Some buildings are "covered" by the reconstructed terrain (blue circles).

Figure 13. A view of the complete 3D model

6. CONCLUSION

We presented in this article methods for building reconstruction, vegetation extraction and DTM extraction from Pleiades simulation images. We can assert that, as these methods were originally implemented for high resolution arial images, considering some adaptations, they can be pertinent for Pleiades simulation images too.

In practice we detected some problems in the linking of steps. We will work on an entire line production more consistent. An other reflexion subject is the representation of vegetation. In our case, we choose roughly to drape images on an "improved" DEM. In dense urban center, where high vegetation is in general isolated trees, it can be more realistic to have an other representation for the vegetation.

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