EVALUATION OF 3D CITY MODEL PRODUCTION FROM PLEIADES-HR SATELLITE IMAGES AND 2D GROUND MAPS

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ABSTRACT

During the past decades 3D building extraction has been a constant topic of research for several universities and cartographic or photogrammetric institutes because there was a great demand for 3D city models in commercial applications. These applications move from electromagnetic propagation for telecommunication to more demanding simulations for acoustic, urban planning, virtual and augmented reality. In most cases, 3D complete roof shapes are required. Year after year radiometric quality and geometric accuracy of new high resolution satellites keep on improving so much so satellite imagery become a real potential solution for the production of such 3D models. This present paper studies the potential of the CNES (French Spatial Agency) Pleiades-HR system, ready to launch in 2007, for the 3D city models production in the case of 2D ground maps availability. First because this Pleiades-HR system, able to acquire tristereoscopic high-resolution panchromatic images, seems well adapted for 3D applications. Secondly because 2D ground maps are now available in many countries, especially in dense urban areas, and are very useful for the automation of the reconstruction process. For the present evaluation very fine image simulations provided by the CNES are used, in addition to 2D ground plans that come from the French cadastral database. The 3D models have been produced with an operational framework able to reconstruct buildings from optical images and 2D ground plans. A 3D reference has been acquired from aerial images with a resolution of 25cm. This reference allows to evaluate from qualitative and quantitative points of view the 3D reconstruction. Finally, the quality of 3D city models produced from the Pleiades-HR images will be discussed in terms of levels of details, geometric accuracy, exhaustiveness and productivity.

1 INTRODUCTION

Over the last decades a lot of automatic building extraction methods have been published. Moreover in industrial context 3D complete vector roof models are produced from aerial images or airborne laser scanning data. However, there still is few paper on 3D city models production from optical high resolution satellites. In (Fraser et al., 2001) a quantitative and qualitative assessment of the use of stereo-IKONOS imagery for generating 3D building models is provided. In (Sohn and Dowman, 2001) an other extraction method from high resolution satellite data is proposed and limits of image resolution are discussed. (Chehata et al., 2003) details an automatic reconstruction of 3D facets using a region matching approach based on hierarchical segmentation of images. These papers show the difficulty to produce 3D city models from spatial images due to problems on the ground resolution and the stereo availability. This present paper is focussed on the potential of the immediate next generation of optical satellites.

In addition to imagery data, large scale 2D cadastral maps are available for many countries. Many publications as for instance (Pasko and Gruber, 1996), (Roux and Maître, 1997) or (Jibrini et al., 2000) have demonstrated the importance of these 2D maps for 3D building reconstruction. In this paper, we try to stay as close as possible to an industrial production context. That is why 2D maps are used to improve our productivity.

The CNES (French Spatial Agency) proposes a new Earth Observation concept called Pleiades which will be operational in 2007. This present paper studies the potential of this new imagery context for the 3D city models production in the case of 2D ground maps availability. Pleiades is an open-ended system, and will be composed of the three following elements :

- a wide field, multi-spectral component SPOT-5, and its successor

- a high resolution optical component (Pleiades High Resolution also known as Pleiades-HR)

- an X-Band radar component (Cosmo-Skymed)

We have to notice that the high resolution optical components (Pleiades-HR), and X-band radar components (Cosmo-Skymed) are the subject of a co-operation between France and Italy on a dual system : ORFEO (Optical and Radar Federated Earth Observation). In this paper we only deal with high resolution optical (Pleiades-HR) image simulations. The Pleiades-HR satellite viewed in flight configuration in Figure 1 is a small satellite. Indeed it will weigh less than 1000 kg to ensure its compatibility with launchers such as Rockot, Soyouz, Vega, etc. The satellites will be placed on a sun-synchronous, phased and almost circular orbit at an altitude of 694 km, with a descending node at 10H15. The orbital cycle will be 26 days. With a roll dispointing capability of 30 deg with respect to the track, world access can be achieved in 5 days with one satellite, and in 4 days with two. The great agility of Pleiades-HR satellites, with their motion capability in roll, pitch, and winding, will allow new acquisition modes which are impossible with SPOT series satellites. One of them is the simultaneous tristereoscopic acquisition mode (Figure 2). The Pleiades-HR ground sampling distance is 70cm on the nadir. On Figure 3 more detailed specifications can be found and we also can refer to (Baudouin et al., 2001) and the website http://smsc.cnes.fr/PLEIADES/. In the following sections, after describing our datasets, our reconstruction framework and the inter-comparison protocol, we will present the results obtained with these images in 3D city models production, and will conclude.

2 PLEIADES-HR SIMULATIONS

The goal of this section is first to explain how these simulations have been processed and then to present datasets. Very fine sim-

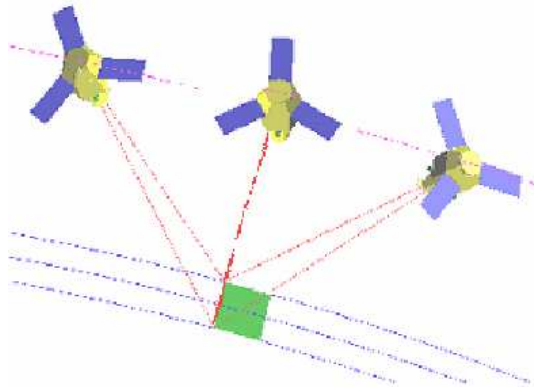Figure 1: Satellite Pleiades-HR in flight configuration

Figure 2: Simultaneous tristereoscopic acquisition mode with Pleiades-HR

Image characteristics	
Panchromatic resolution	0.7m on nadir
	[PAN : 480-830 nm]
Swath	20km on nadir
Spectral bandwiths	blue : 430-550 nm
Resolution : 4 times	green : 490-610 nm
the resolution of the	red : 600-720 nm
panchromatic mode	PIR : 750-950 nm
Agility	
Roll 60 deg	25 seconds
Pitch 60 deg	25 seconds
Location Accuracy	
with a ground control point	1m
with no ground control point	better than 15m RMS
Acquisition capability	
Up to 450 images per day and per satellite	
Acquisition Examples	
stereo over 60 km with B/H ratio 0.2	
stereo over 120 km with B/H ratio 0.3	
tri-stereo over 20 km with B/H ratios 0.15 - 0.15	
tri-stereo over 60 km with B/H ratios 0.2 - 0.2	

Figure 3: Pleiades-HR satellite characteristics.

ulations of two stereoscopic 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. Figure 5 shows the same buildings on the 25cm aerial images and on the Pleiades-HR simulations with a 70 cm ground resolution.

Figure 4: 2D cadastral polygons on a building block

Figure 5: Pleiades-HR simulation image (left) and 25cm aerial digital image (right)

For this study we have worked on two areas which correspond to different urban landscapes. The first one which is showed on Figure 6 is a part of the downtown of Amiens which is a city of the north of France. The second one is a little residential periurban area near Amiens where buildings are essentially small individual houses with gardens (Figure 7). For both datasets, there are two data contexts. The first one is a Pleiades-HR stereoscopic

triplet context, that is the focus of this paper. The second one is original digital aerial image triplet context, it allows to produce a reference 3D model which make evaluations possible.

Figure 6: Amiens downtown reconstruction area

Figure 7: Amiens periurban reconstruction area

3 RECONSTRUCTION FRAMEWORK

All the 3D models has been produced with a reconstruction framework based on previous works (Flamanc et al., 2003), (Maillet and Flamanc, 2004). In the last version of this reconstruction framework, the user can only edit the 2D ground footprint of buildings, and all the 3D roof models are automatically produced using these 2D footprints and a DSM (see Figure 8). A 2D cadastral map gives an initial version of these 2D ground footprints, but the operator has to check, complete and edit them in order to make the automatic 3D reconstruction possible. This manual edition process is necessary because in cadastral maps, the polygons geometry is based on tax criteria rather than physicals ones. For instance, two very different parts of a building like a high tower and an adjacent low shopping arcade can be in a same cadastral polygon. In this case, the operator has to split this polygon to create two building footprints because our 3D reconstruction process can not managed this huge 3D difference. During this interactive process, the operator can switch between the DSM and a true orthoimage visualization to achieve these controls and editions.
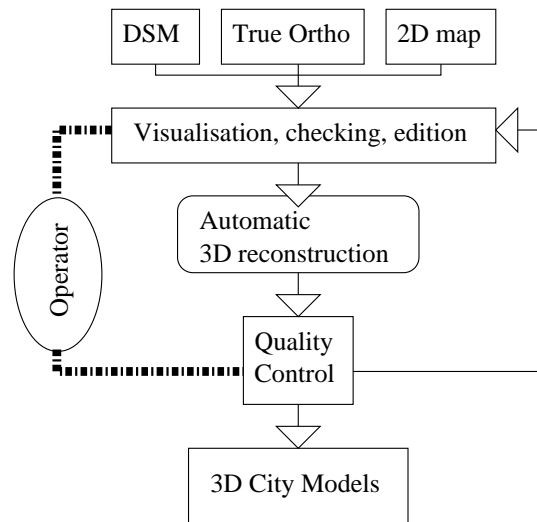

Figure 8: Reconstruction framework

The automatic 3D reconstruction is a model driven approach: for each building footprint several 3D roof shape hypotheses are inferred (Figure 9). Each hypothese is then fitted on the DSM, and the best scored solution is proposed to the user acceptance. More precisely, the hypotheses generation process is focussed on flat roof, or building with a symmetric roof around a central ridge. Of course, it is a very restricted family of possible roof shapes, but with an appropriate 2D footprint preprocessing it is enough for precise and complete 3D city models (Figure 11). Moreover, with this range of ground resolution (between 50cm and 1 m), it is necessary to use more constrained 3D building models to ensure a correct robustness.
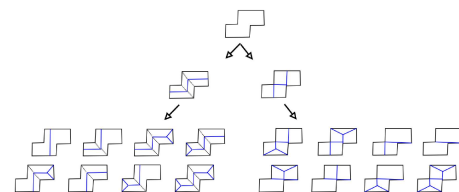

Figure 9: 3D roof shape hypotheses inferred from a 2D building footprint

4 EVALUATION PROTOCOL

On each dataset (Amiens downtown and Amiens periurban) we have produced 3D city models from cadastral maps and Pleiades-HR stereoscopic triplets. In addition, on the same areas, other 3D city models have been achieved from cadastral maps and the original 25cm aerial images in order to constitute the 3D references which are used in our evaluations. Four quality indicators have been selected to compare and evaluate 3D models produced in the different contexts :

- Height geometric accuracy

- Productivity : the number of buildings per hour

- Level of details : roughly estimated with the number of facets per km^2

- Exhaustiveness : estimated with the ratio of reference buildings surface covered in the reconstructed model

The term 'building', used in the expression of the productivity indicator, corresponds with a roof which can be modeled with a continuous surface with no altimetric discontinuities. We call facets only 3D plane polygons concerning the roof and not the vertical walls. Concerning the height geometric accuracy indicator we have basically compared 3D models from Pleiades-HR with 3D models from 25cm aerial images. The estimations have been achieved through the punctual height difference method. The method and his limits are detailed in (Abbas, 1994). Through a regular grid on the overlap area between two vector 3D models we calculate an image of height differences. The ground resolution of the grid is the same as the resolution of images used for the reference : 25cm. The pixels of this height difference image constitute our statistical population. We estimate our accuracy indicators through two iterations. First we estimate the median and the RMS after rejecting outliers over 5m. Then after re-centering on the first height median estimated and rejecting values over 3xRMS we achieve the second estimation.

5 RESULTS

All the numerical results are summarized in Figure 10. The very first important point to notice is that these new satellite tristereoscopic images can be used to produce metric 3D city models. Then differences between dense urban area (RMS = 0.70 m) and periurban area (RMS = 0.92 m) can be explained by the difference on the average building size in these two types of landscapes. In the periurban context there are mainly small pavillons, so the roof facets are smaller than in the dense urban area and the DSM fitting process is then less reliable. Exhaustiveness is quite good (more than 90%) but this performance closely depends on the quality of the initial 2D cadastral maps. Another important point in these results is the differences in productivity between Pleiades-HR context and aerial images one. In dense urban areas, due to the difference of resolution, the operator can operate an efficient generalization on the Pleiades-HR images and the productivity is better than on aerial images. On the opposite, in surburb areas, with small and isolated pavillons, the interactive edition becomes more difficult and the productivity falls.

6 CONCLUSION

We have presented a study of the CNES Pleiades-HR system ready to launch in 2007 for 3D city model production in case of 2D ground maps availibility. These system specifications seem well adapted for 3D model production especially because of the great agility of satellites in roll, pitch and heading which make simultaneous tristereoscopic acquisition mode possible. Through evaluation processsus it appears clearly that metric 3D city models can be produced from these images although there are some difficulties in case of small individual houses of periurban landscapes. There is no doubt that this new generation of satellite will be a real alternative for 3D city model production.

REFERENCES

Abbas, Y., 1994. Base de données vectorielles et erreur cartographique. Problèmes posés par le contrôle ponctuel. Une méthode alternative fondée sur la distance de Hausdorff: le contrôle linéaire. PhD thesis, Univ. Paris VII.

Baudouin, A., Boussarie, E., Damilano, P., Rum, G. and Caltagirone, F., 2001. Pleiades : A multi mission and multi cooperative program. 52nd International Astronautical Congress.

Chehata, N., Jung, F., Deseilligny, M.-P. and Stamon, G., 2003. A region-based matching approach for 3d-roof reconstruction from high resolution satellite stereo pairs. In: APRS:DICTA'03, Vol. II, pp. 889–898. Sydney, Australia.

Flamanc, D., Maillet, G. and Jibrini, H., 2003. 3d city models: an operational approach using aerial images and cadastral maps. In: Photogrammetric Image Analysis, Munich, pp. 53–58.

Fraser, C. S., Baltsavias, E. and Gruen, A., 2001. 3d building reconstruction from high-resolution ikonos stereo-imagery. In: B. B. Verlag (ed.), Automatic Extraction of Man-Made objects from aerial and space images, Ascona, pp. 331–344.

Jibrini, H., Paparoditis, N., Deseilligny, M. and Maître, H., 2000. Automatic building reconstruction from very high resolution aerial stereopairs using cadastral ground plans. In: IAPRS, XXXIII (Amsterdam).

Maillet, G. and Flamanc, D., 2004. Comparison of aerial images, satellite images and laser scanning dsm in a 3d city models production framework. In: XXth ISPRS Congress, Istanbul.

Pasko, M. and Gruber, M., 1996. Fusion of 2d gis data and aerial images for 3d building reconstruction. In: International Archives of Photogrammetry and Remote Sensing, Vol. 31, pp. 257–260.

Roux, M. and Maître, H., 1997. Three-dimensional description of dense urban areas using maps and aerial images. In: B. B. Verlag (ed.), Automatic Extraction of Man-Made objects from aerial and space images II, pp. 311–322.

Sohn, G. and Dowman, I., 2001. Extraction of buildings from high-resolution satellite data. In: B. B. Verlag (ed.), Automatic Extraction of Man-Made objects from aerial and space images, Ascona, pp. 345–355.

Thom, C. and Souchon, J. P., 2001. Multi-head digital camera systems. GIM International 15(5), pp. 34–37.

Area (surface)	Amiens Downtown (0.22 km^2)		Amiens periurban (0.07 km^2)	
Images	Simulation Pleiades-HR tristereo	Reference Aerial images tristereo	Simulation Pleiades-HR tristereo	Reference Aerial images tristereo
Resolution on nadir (m)	0.70	0.25	0.70	0.25
Base/height	0.2 - 0.2		0.2 -0.2	
Nb cadastral polygons	567		102	
Nb facets	790	1097	183	255
Nb buildings	467	653	115	135
Productivity (buildings/h)	**248**	**224**	**345**	**810**
Nb facets/km^2	**3591**	**4986**	**2614**	**3643**
Exhaustiveness	**93.0%**	**100.0%**	**94.7%**	**100.0%**
Rejection	3.89%	0.%	3.48%	0.%
RMS (m)	**0.70**	**0.**	**0.92**	**0.**

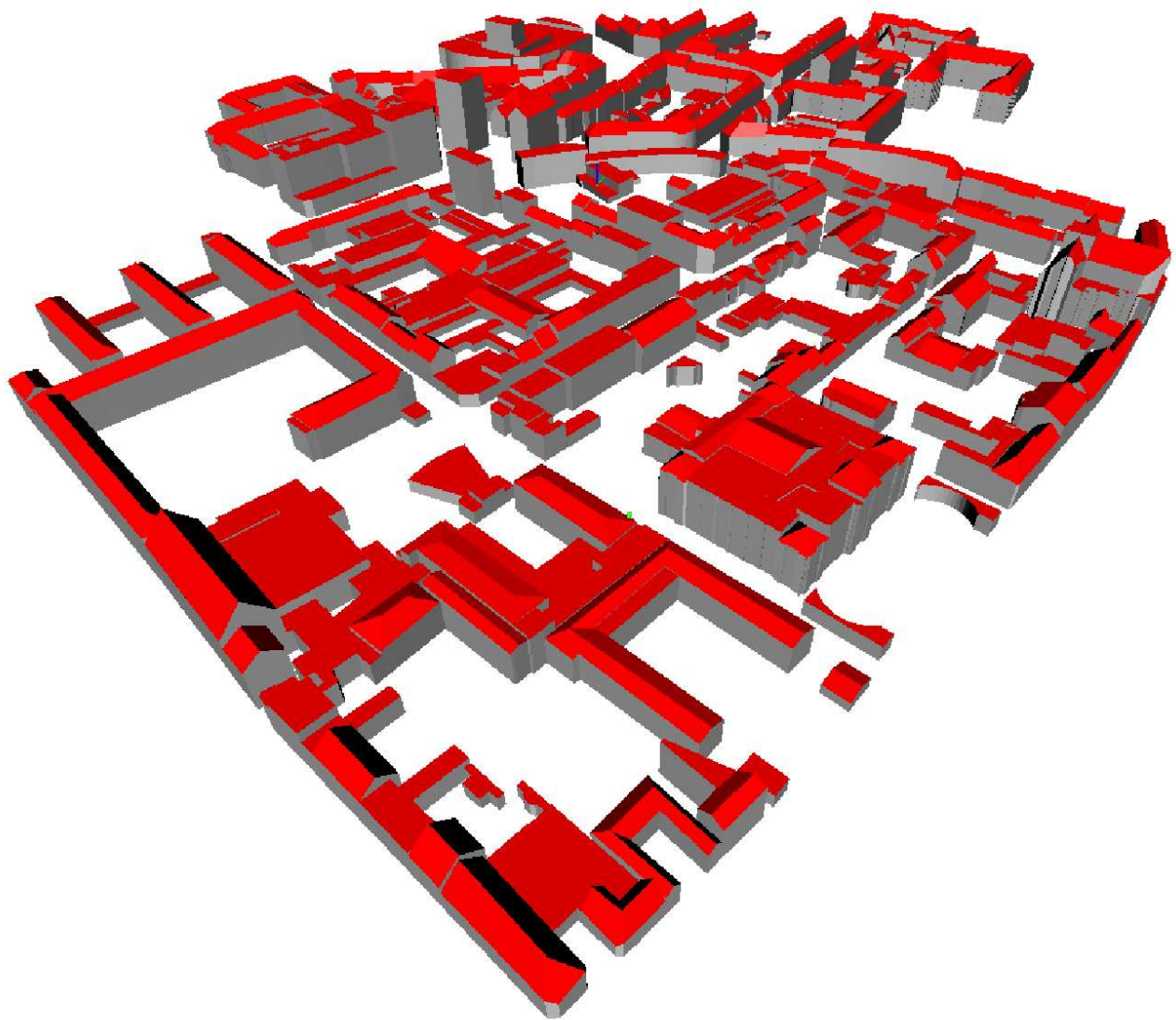Figure 10: Technical characteristics and results.

Figure 11: 3D Model from Pleiades-HR images and cadastral maps on downtown area