PRODUCTION OF VEGETATION INFORMATION TO 3D CITY MODELS FROM SPOT SATELLITE IMAGES

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KEY WORDS: Forest mapping, satellite imagery, 3D city model, atmospheric calibration, 3D visualisation

ABSTRACT:

The paper presents a methodology to produce forest parameters and tree instances to large area 3D maps or city models from satellite images. The process flow includes the calibration of the satellite image, the forest parameter estimation, the generation of tree instances from the forest parameters, and the integration of the tree instances to 3D city model and visualisation. Due to the calibration, forest parameter models developed for other areas can be used in the estimation.

SPOT satellite images were used to generate tree instances to a Finnish 3D city model. The number of trees/ha, the mean diameter/ha, the stem volume/ha, and the tree type (coniferous or deciduous) were estimated to each pixel of the SPOT image. Tree instances based on these parameters were entered to 3D visualisation software with the state of art city model. The results show, on one hand, the discrepancies between the 10 meter satellite image and the aerial image, like some trees on the roof or in the street. On the other hand, it shows the high geometric quality of the SPOT satellite image and its suitability to the production of tree instances to standard city models.

1. INTRODUCTION

1.1 Background

3D city models and maps are produced from existing data bases or from new aerial imaging and laser scanning. Municipal and national base maps, building and road databases and land cover databases are used for the generation of 3D city models for planning or simulation purposes.

The state of art methods use aerial imaging and laser scanning for the production of maps and city models. Besides the accurate elevation, the laser point cloud is useful also for the detection and identification of tree tops, tree crowns, roof facets, and vegetation layers of different height.

When up to date information is needed on the vegetation layer of large areas, high resolution (1 to 10 meter) satellite images are a feasible alternative. It is often also the only alternative to map the vegetation layer, which is continuously changing, but at the same time it is not updated as frequently to the land cover or map databases as the other map layers. The resolution of satellite images is not as high as for aerial images, but accurate enough for the vegetation cover whose boundaries seldom are very clear even in the ground.

1.2 Forest mapping

LANDSAT TM and ETM images and SPOT images have been used largely in operative forest inventory and mapping for large areas. Methods have been developed to estimate stand-wise forest parameters from satellite image reflectance values. The RMSE figures that have been achieved in the estimation of forest parameters from satellite images are 25 years for mean age, 5 m2/ha for mean basal area, 700 trees/ha for number of stems, 5 cm for mean diameter, 5 m for mean height and 50 m3/ha for stem volume.

The model between the wavelength channels and the forest parameters is quite linear, except the saturation in high density forest. For instance with LANDSAT ETM images the reflectance reach the maximal levels when stem volume is about 200 m2. When resolution increases (QuickBird and IKONOS satellite images and aerial images), and reflectance values do correspond to individual trees, single trees can be mapped (Korpela, 2007, Astola et al, 2004), and also dense forest with stem volume more than 200 m3/ha can be mapped correctly.

1.3 Satellite image calibration

The mapping of forest parameters from satellite images needs traditionally extensive ground measurements to calibrate the results. Important objective in current studies is related to the creation of reflectance databases and reflectance calibration of the satellite images, so that common models can be used in the estimation of forest parameters and the number of ground measurements can be reduced. Good results have been achieved in the reflectance calibration of LANDSAT ETM images when the atmospheric aerosol optical density (AOD) surface is be calculated from the image itself and used in the atmospheric correction. Kaufman, 1997, presents the method to calculate AOD values from the ratio of the red and mid-infrared top of atmosphere reflectance. This methodology was used for instance in the Finnish CORINE 2000 project to produce the

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nationwide reflectance mosaic from LANDSAT ETM images (CORINE, 2005).

1.4 Objectives

The paper presents a method for the generation of tree instances from SPOT satellite images to 3D city models. It is based on the reflectance calibration of the satellite image and the forest parameter estimation with existing models without the need of ground reference.

2. METHOD FOR THE GENERATION OF TREES

2.1 General

The method is based on the reflectance calibration of the satellite image so that common models can be used in the estimation of forest parameters, and the method can be applied also to areas from where ground measurements or other reference data is not available

The other basic idea in the process is the utilization of a ratio based vegetation index in the delimitation of forest areas from other areas. Channel ratios between two close wavelength channels reduce the effects of atmospheric parameters and same threshold can be used for different images.

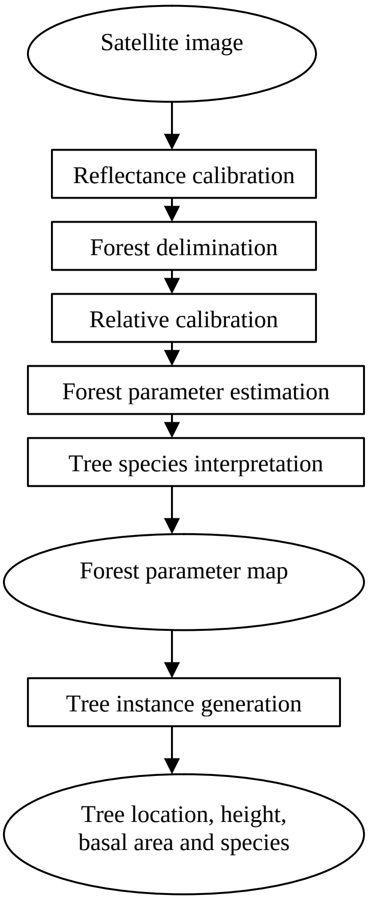

Figure 1. Diagram of the tree generation process.

Figure 1 shows the phases of the process to generate tree instances from satellite images.

2.2 Reflectance calibration

The calibration of the pixel values into TOA (top of atmosphere) reflectance values is done using the calibration coefficients from the SPOT leader file. The surface reflectance values are then calculated from TOA reflectance values with SMAC code (Rahman and Dedieu, 1994), which makes also the atmospheric correction based on standard atmospheric models and parameters. The reflectance calibration can be refined with AOD calculation from the image itself.

In the next step the NDVI image is calculated from the surface reflectance image. The NDVI (Normalized Difference Vegetation Index) values are calculated from the red and near infrared reflectance values. The forest areas are delimited from the image by threshold of the NDVI.

The reflectance calibration is refined by relative calibration of the new image into the model image, ie. the image used in the development of the forest parameter models. The forest area's reflectance values are scaled to the mean and standard deviation of the model image's reflectance values in forest areas.

2.3 Forest parameter models

The linear models for the forest parameter estimation are based on Landsat TM satellite images of 30 meter resolution over the Ruokolahti area in Eastern Finland. Table 2 show the regression statistics between reflectance values from two Landsat TM images and the ground measured stand wise forest parameter values.

	27.8.97	22.7.98	27.8.97	22.7.98
Parameter	r	r	RMSE	RMSE
Age (years)	-0.43	-0.48	15.22	14.81
Basal area (m2/ha)	-0.67	-0.66	5.22	5.57
Nr of stems (nr/ha)	0.45	0.46	686.4	681.9
Diameter (cm)	-0.60	-0.61	4.72	4.65
Heigth (m)	-0.59	-0.62	3.81	3.68
Stem volume (m3/ha)	-0.61	-0.61	43.84	44.01

Table 2. Regression statistics between Landsat TM images of 27th August 1997 and 22nd July 1998 and ground measured stand wise forest parameters.

The model definitions are based on 2 774 269 observations. The ground measurements were stand wise values and the satellite values were pixel wise values. The models based to the image of 22nd July 1998 were chosen for the forest parameter estimation from SPOT satellite images.

The proportion of the deciduous and the coniferous trees is not estimated by linear modelling like the other forest parameters. Deciduous and coniferous trees are separated with a threshold from the near infrared reflectance values. However, because of the image calibration procedure, a constant threshold is assumed to apply and is used for different images.

3. TEST MATERIAL AND CALIBRATION

3.1 Test material

The test site is the Otaniemi area located in Southern Finland 5 km west from Helsinki.

Two SPOT satellite images were used for the test. The first satellite image is a SPOT 2 HRV image of row and path 73-226, with 20 meter resolution and acquired 7th June 1994.

The second image is a SPOT5 A1 level HRG2 image of row and path 73-226, with 10 meter resolution and acquired 5th September 2005 at 09:52:53 UTM.

The images were rectified by standard procedure to the Finnish map coordinate system. The mean residual error of the affine transformation was 10 meters for the June 1994 image and 6 meters for the September 2005 image.

The images cover the 60 x 60 km^2 area of a SPOT image, and include the Otaniemi test site of about 6 km^2. The area of the images is mostly built areas, but includes also large forested areas.

The state of art city model of Otaniemi area is used as reference data, to which the tree instances are integrated. The model is made from LiDAR data and aerial imagery acquired in 2001. The laser scanning was done with about 6 points/m^2 and the pixel size of the aerial image was 5 cm.

The city model includes the terrain elevation map, 3D buildings and tree instances, with tree location, height, crown diameter and tree species. The elevation map, the height of the building roofs and the tree parameters are mapped from laser points. The roof boundaries of the buildings are mapped from the aerial image. The model includes also the orthophoto to give the texture and the map components not identified and mapped as separate objects. The orthophoto is rectified with the surface model from LiDAR points.

3.2 Calibration

Table 3 shows the channels of the images and the calibration coefficients, sun angles and atmospheric parameters used in the conversion of the digital number into radiance, TOA reflectance and surface reflectance.

Calibration coefficients and atmospheric parameters	SPOT 2 7.7.1994	SPOT 5 5.9.2005
0.50 – 0.59 µm	0.104	0.059
0.61 – 0.68 µm	0.123	0.052
0.78 – 0.89 µm	0.205	0.098
1.58 – 1.75 µm	n.e.	0.079
Solar Zenith (º)	38.5	53.0
Solar Azimuth (º)	159.5	170.0
Aerosol Optical Density	0.20	0.10
Water Vapour (g/cm^2)	2.0	2.0
Ozone (Dobson units)	350	350
Pressure (hPa)	1013	1013

Table 3. Parameters for the reflectance calibration of the two SPOT images.

4. RESULTS AND DISCUSSION

Table 3 show the range of the forest parameters estimated from the SPOT satellite images of June 1994 and September 2005.

	June 94	June 94	Sept 05	Sept 05
Parameter	min	max	min	max
Age (years)	0	44.1	4.5	43.3
Basal area (m2/ha)	1.6	21.7	0.6	20.6
Nr of stems (nr/ha)	1170	2258	1188	2047
Diameter (cm)	1.0	15.9	3.2	16.3
Heigth (m)	2.1	13.5	2.6	13.5
Stem volume (m3/ha)	2.9	153.7	0	144.4

Table 3. Ranges of the forest parameters estimated from the SPOT satellite images of June 1994 and September 2005.

Figure 4 shows the tree instances generated from the forest parameters based on the September 2005 SPOT image and integrated to the Otaniemi area city model.

Figure 4. Tree instances generated from the SPOT satellite image 2005 and integrated to Otaniemi city model. ©Terrasolid 2001, © VTT 2006.

Quantitative evaluation of the results has not been made and the evaluation was based only to visual inspection of the trees integrated to the city model and visual comparison of photographs taken in the test area and the corresponding views from the virtual model.

Visually the generated trees fit well to the 3D city model. Because of the box type pixels of the satellite image, the corners of the pixels can be seen in some cases, creating trees on the street. This can be however eliminated by straightening or smoothing the boundaries of the forested areas.

The tree instances were generated from SPOT satellite images having 10 and 20 meters pixel sizes. With the 10 meter imagery the rows of single trees are not detected. With 20 meter images also rows of tree pairs are left undetected. Optimal results for this kind of tree mapping could be achieved from 5 meter resolution satellite images.

The critical point of the method is the relative calibration of the new image to the image which has been used for the forest parameter model development. The method assumes that the range of the forest parameters is the same in both images. This is usually fulfilled at a reasonable extent when the image covers an area of thousands or ten thousands of kilometres, which is the case with SPOT, Landsat and IRS type of imagery.

5. CONCLUSIONS

The paper present a method chain to create tree instances to city models from SPOT satellite images. It is based on the reflectance and relative calibration of the satellite image, so that same forest parameter models can be used in different areas and with different images.

The integration of the results from the forest parameter estimation into a state of art city model shows that the SPOT satellite images are a feasible source to generate realistic tree layers to large area 3D maps and city models. This is important especially because up to date vegetation information is rarely available from existing land cover and forest databases.

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ACKNOWLEDGEMENTS

The authors want to thank the Finnish Funding Agency for Technology and Innovation and the two companies participating to 3D Terrain project for funding the research related to the production of city model components from satellite images. Also we are grateful to Terrasolid and Helsinki City Measurement Department for providing reference city models and 3D map data over Otaniemi and Helsinki areas.