3D roof modelling for accurate assessment of solar potential

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Abstract

It is foreseen to develop a "smart city" service aimed to provide accurate assessment of solar energy potential for buildings under the scope of the iSCOPE "interoperable Smart City services through an Open Platform for urban Ecosystems" (ICT PSP) project funded by the European Commission and "Spatial, environmental, energy and social aspects of developing settlements and climate changes – mutual aspects" project funded by the Serbian Ministry of science. The service will be deployed for the town of Indjija as the pilot site. 3D model of roofs is required to serve as the information basis for the service. The paper is describing an efficient automated methodology for generating the 3D model of single-plane and 2-plane roofs from rather coarse DSM (Digital Surface Model) created automatically from stereo-photogrammetry. The assessed accuracy of the generated model is proved to be sufficient for the purpose.

Key words: 3D urban models, solar energy potential assessment, Digital Surface Model, „smart city" service

1. Introduction

The need for 3D "Urban Information Models" is clear. They are the base that "smart city" services are built on. It is of particular public interest to develop "smart city" services that support sustainable energy policy, namely energy efficiency and renewable energy policy. A "smart city service" aimed to provide the information on solar potential at building level requires 3D model of roofs. Such model did not exist for the territory of the town of Indjija, for which the "smart city" service is supposed to be developed, and therefore had to be created.

Currently, 3D urban models are produced by conventional aerial photogrammetry or from high density points from airborne laser scanners (i.e. [3], [4]), but both techniques offer solutions that are expensive or time consuming. DSM (Digital Surface Model) is a product suitable for generation of 3D models of buildings. To achieve accurate DSM through photogrammetric techniques, the data redundancy, namely multiple measurements for one point on the ground, is required. It means that there is the need for a number of stereoscopic pairs from which single point on the ground is seen. [1] report vertical accuracy achieved with this method of 35-60cm for DSM with spatial resolution of 2m from source imagery at 60cm. Contrary to this [2] generated DSM of accuracy close to 2 m from single IKONOS (0.8 m pixel) stereo pair with the use of commercial software packets. However, this accuracy is not suitable for the purpose of the solar potential assesment "smart city" service. This paper describes the algorithm used to produce high quality 3D model of roofs in an efficient way from DSM (Digital Surface Model) created automatically from stereo-photogrammetry.

2. “Smart city” service for assessment of solar energy potential at building level

The smart service is aimed to provide through a 3D web client cartographic and attribute data on: a) Solar potential of the roofs, for each roof (users will be able to chose a certain day of the year and weather conditions as well as other options like monthly and annual averages…); b) Estimation of costs for creation of solar power panels, for each roof; c) Estimation of the time for return of investment, for each roof (depending on the electricity costs, energy related policies…); d) Existing solar installations and remaining solar power potential, for each roof.

Such service might have a significant impact on a local energy policy, raising awareness of energy efficiency and renewable energy sources among decision makers (local government), enterprises and common citizens. Investments in the sector would consequently bring benefit to the community through increase of energetic independence and savings on electric bills, development of the new economic branch on the local level and leadership position in terms of both being environmentally responsible town and the use of “smart city” services for the benefit of citizens.

3. Creation of 3D model of roofs

3.1. Input data

As derived from aerial photos stereoscopic coverage, DSM usually represents the canopy of landscape in which heights information is all above-ground details, including top of the buildings and trees [1]. The DSM that was used in this research is generated in SOCET Set software from single stereopairs of digital airborne photo sensors. However, the result tends to be very noisy (Fig. 1, left), providing low vertical accuracy and precision to create 3D model of roofs.

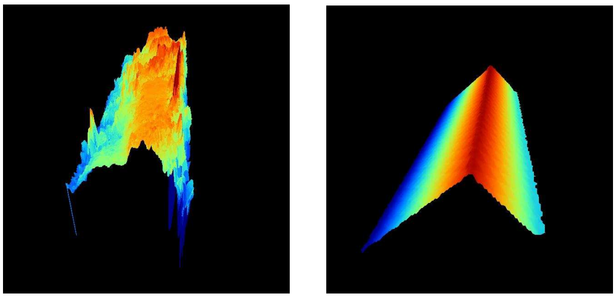

Fig. 1. An example of raw DSM of the 2-plane roof used in the experiment (left) and final 3D model of 2-planes roof (right)

There were overall 2208 shed (single-plane) roofs, which makes around 21% of all roofs in Indjija, and 4506 gable (2-plane) roofs (~42%) [9]. 3D models of more complex roofs (3896- ~37%) will have to be produced by conventional methods, unless some other form of production from the DSM is developed in the meantime.

Another data used in the process of filtering the DSM to create the 3D models is the shapefile with polygon data representing outlines of the objects in Indjija. Each polygon has an attribute indicating whether the roof of the object is single or 2-plane. This data has been useful for extracting the DSM of the roofs from the DSM of the entire town area.

3.2. Algorithm for automated roof surface generation

An algorithm is designed to produce 3D model of roofs in raster format [9]. The algorithm is consisted of 2 parts: a) discrimination of single-plane and 2-plane roofs (polygon .shp file indicting the type of the roof was available) and b) filtration of the DSM. In case of single plane roof, the DSM was filtered by defining first order polynomial trend surface [5] using Least Squares Method. For each “roof” a vector point cloud was derived from the raw DSM. The Least Squares Method was used to define trend surface and for each point residuals and Cook’s distances [7] were calculated. After points with residuals greater than Cook’s distance had been deleted, new trend surface was calculated. The process was repeated until residuals were below 0.5 (Fig. 2).

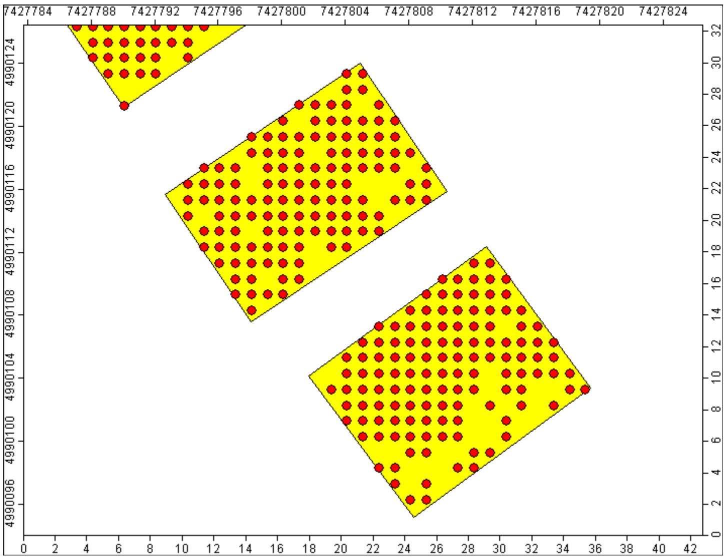

Fig 2. Cloud of remaining points after filtering for each building. Final DSM is created from the points.

In the case of 2-plane roofs, second order polynom trend surface [5] is calculated using Least Square Method (Fig. 3). The pixels of the trend surface are subsequently clustered in 2 groups based on their aspect value using Hill-Climbing method [6]. Finally, a 2-plane roof is reduced to a case of 2 single plane roofs. In both cases the process is iterative, leading to the smooth roof surfaces (Fig. 1, right). The result is the number of filtered DSMs of roofs representing 3D roof models that were later used as a base input for the estimation of the solar potential service.

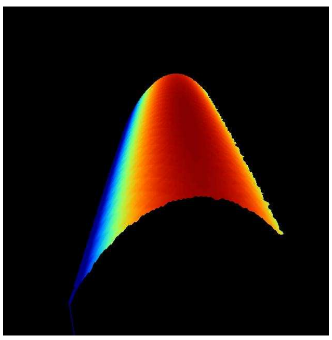

Fig. 3. 2-plane roof approximated by the second order polynom trend surface

3.3. Accuracy assessment

Since for the purpose of assessment of solar energy production capabilities there is the need for data on aspect and slope [8] of the roof planes, the accuracy of those parameters, as well as the height values of the pixels in the generated roof models were assessed. The parameters derived from the filtered DMS were compared with the models produced by manual methods of classical photogrammetry (that we can consider of high quality) (Tables 1 and 2).

Table 1. Differences in heights, aspect and slope for the case of single plain roof

	Number of pixels	**Minimum**	**Maximum**	**Mean**	**Standard deviation**
Height (m)	17395	0.000314	0.379614	0.193921	0.103811
Aspect (°)	17395	0	0.922687	0.001293	0.01794
Slope (°)	17395	0.000228	0.721203	0.248249	0.151658

Table 2. Differences in heights, aspect and slope for the case of 2-plains roof

	Number of pixels	**Minimum**	**Maximum**	**Mean**	**Standard deviation**
Height (m)	1065	0.000197	0.486569	0.120322	0.103383
Aspect (°)	1065	0	12.5	1.32686	3.154805
Slope (°)	1065	1.690043	10.583567	4.759772	1.928329

The results show that achieved vertical accuracy is in both cases is around 20 cm. However, mean aspect and slope difference of respectively 0.001293 and 0.248249 decimal degrees in the case of single plane roof are lower than in the case of 2-plains roofs (1.32686 and 4.759772) which have also higher standard deviations of the differences. Nevertheless, we can consider that both 3D models are produced with the sufficient accuracy for the purpose.

3. Conclusion

Geometrically accurate 3D model of roofs is an essential component of a “smart city” service for solar energy potential assessment at building level. Production of the data is generally expensive and time consuming. The method presented in this paper provides a convenient, highly automatic and time-and-resources saving solution for the single-plane and 2-plane roofs cases. The results produced here, in both single-plane and 2-plane roofs cases, show good accuracy of the parameters relevant for the service, namely height, aspect and slope. For more complex roofs, further research on the ability of 3D model production from automatically–created DSM is necessary.

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