AIRBORNE LASERSCANNING DATA FOR DETERMINATION OF SUITABLE AREAS FOR PHOTOVOLTAICS

T. Voegtle, E. Steinle, D. Tóvári

Institute for Photogrammetry and Remote Sensing (IPF), University of Karlsruhe, Englerstr. 7, 76128 Karlsruhe, Germany

(voegtle, steinle, tovari)@ipf.uni-karlsruhe.de

KEY WORDS: Airborne Laserscanning, 3D Modelling, Building, Application, Photovoltaics, GIS

ABSTRACT:

In this paper, airborne laserscanning data are used to select suitabel areas for the installation of photovoltaic devices automatically. Building roofs are preferable locations for photovoltaics considering shadowing effects but minimum size, exposition and slope of the roof planes have to be taken into account. To obtain such detailed information, laserscanning data combined with digital topographic data (building contour lines) are analysed. For extraction of roof planes an algorithm developed as part of a 3D building modelling system was applied. As result a mathematical description of each plane is obtained which is used to determine the required features *size*, *exposition* and *slope*. By means of digital contour polygons the planes and their parameters are assigned to individual buildings. The selection of favourable buildings for location of photovoltaic installations is performed by a GIS database management system. For testing purposes this method was applied to an urban area of about 4 km x 2 km with complex roof structures, building blocks etc. to prove the capabilities as well as the limitations of this approach. Problems occur at some roof planes where laser point density is lower than in other parts. In these cases more than one plane may be extracted due to significant undulations inside the point cloud. Additionally not all disturbing objects (e.g. dormers, chimneys, antennas etc.) were excluded totally (as it is necessary for photovoltaic areas). Therefore, supplementary information like aerial images should be integrated in this analysis in the future to detect and delineate the areas more precisely, which are effectively available for the application of photovoltaics.

1. INTRODUCTION

In the last three decades it became more and more obvious that the amount of fossil fuels are limited and accordingly the development of costs was enormously in this time. Therefore, private investors as well as administrative departments show an increasing interest in renewable energies. In this context the strategy to favour huge central power stations exclusively has changed. Governments have begun to support also local (decentral) energy production, e.g. by wind plants or photovoltaic installations. Photovoltaics transfer the energy of sun radiation into electric current. Therefore, to utilise this technique some restrictions have to be taken into account. First of all such an installation should have a minimum size, a specific azimuthal orientation (exposition) and slope for a most efficient energy production. On the other hand no shadowing effects, e.g. caused by higher buildings or vegetation in the surrounding, should occur and influence the duration and intensity of irradiation. For this an elevated and exposed position has to be choosen. Thus, building roofs are preferred locations to place photovoltaic installations. For planing purposes and estimation of financial support detailed information about suitable areas for photovoltaics and the potential of energy that can be obtained is necessary.

The aim of a regional planning authority in the state of Baden-Wuerttemberg (Germany), *Regionalverband Nordschwarzwald*, in cooperation with the State Institute for Environmental Protection, *Landesanstalt fuer Umweltschutz Baden-Wuerttemberg*, is it to support private initiatives to install and operate photovoltaic devices, i.e. to inform houseowners systematically about their possibilities according technical and financial issues (estimation of the amount of energy delivered by photovoltaics individually for each building, costs, governmental aid etc.).

An automated approach was developed at our institute and a practical application for a test area in urban environment was carried out to determine the basic plane features

- *size*
- *exposition*
- *slope*

of individual building roofs. Subsequently a selection of suitable roof planes – and the related buildings – has to be performed by means of a GIS database management system. At a later date this method will be applied to the whole area of the region of about 35 km x 100 km (Figure 1) and the potential of photovoltaics will be analysed automatically.

In the following sections the data used for this approach are described. Subsequently the methodology will be explained inclusively the extraction of roof planes, the determination of the plane features and their assignment to individual buildings. In the next section the application of this method and first results will be shown. Here one aspect will be also the problems and limitations of this procedure. A conclusion and future prospects on remaining and additional work will be given at the end.

Figure 1. Geographical position and area of the regional planning authority (*Regionalverband Nordschwarzwald*).

2. DATA AND TEST AREA

For this approach mainly two different data sets are essential, airborne laserscanning data for derivation of the roof structures and building contour polygons for relating the extracted roof planes to individual buildings. The latter is necessary although there exist a lot of methods for detection and 3D modelling of buildings from laserscanning data (for an overview see e.g. Foerstner, 1999; Baltsavias et al., 2001) but none of these can deliver individual houses out of a building row or a building block with nearly the same height and slope of roofs (which is very common in urban areas, cf. Figure 3).

The data for this development are provided by the *State Institute for Environmental Protection, Baden-Wuerttemberg*, in the context of a feasibility study. They originate from the Spatial Information and Planning System (RIPS) of this department and the database of the State Survey Authority Baden-Wuerttemberg (*Landesvermessungsamt LVA*).

The laserscanning data are available in digital format for the whole area of this state and are acquired by the well-known ALTM scanner (Optech). The average laser point distance on ground is about 1.5 m , the positioning accuracy is about ±0.3 – 0.4 m and the accuracy in height is about ±0.10 – 0.15 m. The laser measurements are classified into two categories, terrain points and non-terrain points (i.e. points on buildings and vegetation objects). This classification was performed automatically by the authorised laserscanning company. To exclude most of the remaining gross errors a subsequent visual inspection of the point clouds and a manual editing procedure of obvious deviations was carried out. As an example Figure 2 shows the point distribution and contour polygons of a small subset of the test area 'Karlsruhe'. A surface model derived by triangulation from the original laser measurements of the same subset can be seen in Figure 3.

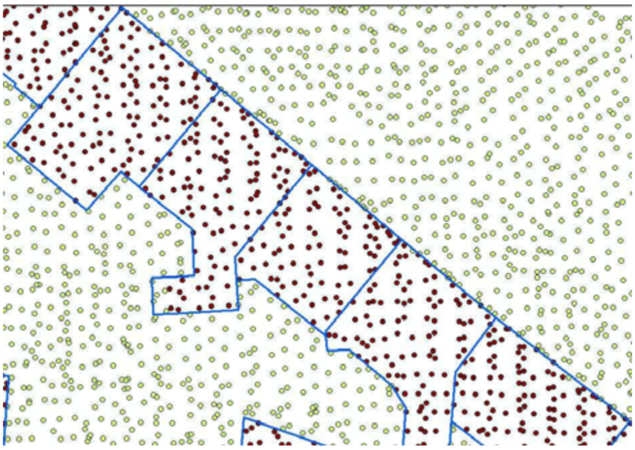

Figure 2. Spatial distribution of laser measurement points and digital building contour polygons (subset test area 'Karlsruhe').

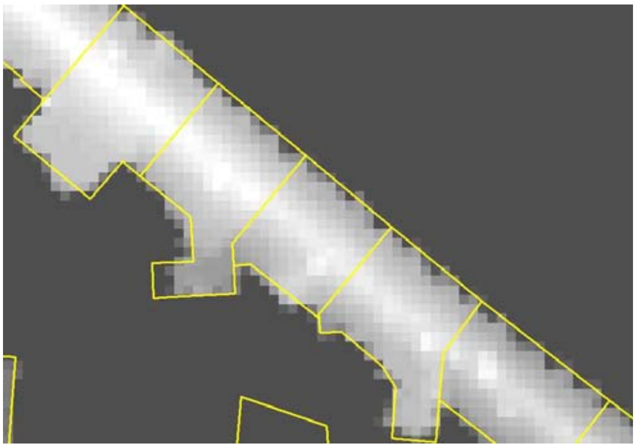

Figure 3. Surface model derived from laser points (grey-coded: dark – low, bright – high) (subset test area 'Karlsruhe').

The digital building polygons are part of the cadastral database that exists for the whole state, too. For identification purposes each contour polygon contains a unique code number (building code number). The geometric data were acquired by terrestrial geodetic measurements and therefore, have a high accuracy of about ±0.01 – 0.02 m. Unfortunately there are no information about heights or roof structures included. Regarding the building polygons it has to be mentioned that the excess length of the roof eaves are not taken into account in these data.

As test area a rectangular section (4 km x 2 km) of an urban settlement (city of Karlsruhe) was chosen as it contains – besides of single buildings – also more complex roof structures, building rows and blocks etc. to prove the capability as well as the limitations of this approach.

3. METHODOLOGY

The basic idea of this approach is to extract roof planes of buildings – which are potentially suitable for photovoltaics – automatically from airborne laserscanning data where each plane got a unique identification number (ID). The necessary features for each plane (size, exposition and slope) are calculated by means of its mathematical description and transferred to a database. Those planes belonging to the same individual building are masked utilising the digital building polygons and the different planes (IDs) inside such a polygon are stored into this database too. Now a selection can be performed based on user-defined conditions (e.g. acceptable slope or exposition values) by means of the database management system.

3.1 Extraction of roof planes

The extraction of (roof) planes cannot be performed directly on the laser points but necessarily on a surface derived from these points. Therefore, in a first step the neighbouring points are connected by a triangulation (e.g. Delaunay) that leads to a surface representation in form of a TIN (triangulated network). At the moment this surface model has to be rasterized because the extraction algorithm is not yet able to handle point clouds directly.

The method for the extraction of plane roof areas is part of the 3D building modelling system developed at IPF (Voegtle & Steinle, 2000; Steinle, 2005) that is originally based exclusively on laserscanning data without additional information like spectral or GIS data. It consists of a specific *region growing* algorithm with a homogeneity predicate (Quint & Landes, 1996). In a first step the algorithm is searching for a so-called seed point or seed area (e.g. 3 x 3 pixel) whose laser points fulfil a user defined starting condition. In this case all points of the seed area must lie in the same plane (initial plane) with only small acceptable deviations, i.e. the point coordinates must fulfil the mathematical equation of a plane. The maximum acceptable deviations depend on the height accuracy of the laser points itself (approx. $\sigma = \pm\ 0.15$ m) and the deviations of real (physical) roof areas from an ideal plane (based on experiences with different data sets this value is about 0.1 – 0.3 m). So the total value of acceptable deviations in the seed area can be set to 0.2 – 0.4 m.

After determination of such an initial plane the region growing algorithm analyses iteratively the adjacent points of the current area. A point is added to this plane if it fulfils a homogeneity predicat. For this not directly the vertical distance of that point to the current plane is used but its so-called *homogeneity probability*. The advantage of this procedure is that at beginning of the growing process (when the area is relatively small) larger deviations are accepted while after an increasingly stabilisation of its spatial orientation (by a larger number of integrated points) the acceptable distances decrease more and more. Therfore, a "drift" of the plane parameters can be prevented.

A plane in $\mathbf{R}^3$ can be written as

$$z(x,y) = a_0 + a_1 x + a_2 y \tag{1}$$

As more than 3 points participate (assured by the size of the seed area) the plane parameters are estimated by an adjustment process. The vertical distance $d_{Pi}\ (x,y)$ of a point P_i with height z_i from the adjusted plane $\hat{z}$ can be expressed as

$$d_{P_i}(x,y) = \hat{z}(x,y) - z_i(x,y) \tag{2}$$

The aim is the minimisation of the error function ε

$$\varepsilon^2 = d^T d = \sum \left(\hat{z}(x,y) - z_i(x,y)\right)^2 \rightarrow \min \tag{3}$$

For determination of the homogeneity probability the membership of that point to the current plane will be assessed by a statistical t-test (*student test*)

$$t = |\bar{d} - d_{P_i}| \sqrt{\frac{n}{(n+1)\ s^2}} \quad < \quad t_{1-\frac{\alpha}{2},f} \tag{4}$$

$\bar{d}$	–	mean distance of the current plane members
n	–	number of current plane points
s^2	–	variance of current plane points
$t_{1-\frac{\alpha}{2},f}$	–	quartile of student distribution of level of significance α and degree of freedom f (f = n-3)

The requested homogeneity probability can now be derived from the distribution function F_f of the *student* distribution

$$P(t) = 2\left(1 - F_f(|t|)\right) \geq P_{\min} \tag{5}$$

If the probability $P(t)$ is higher than a user-defined minimum value P_{min} the point will be added to the current area and a new estimation of the plane parameters will be performed. The procedure stops if no further neighbouring points can be found which fulfil condition (5). Each plane gets a unique identification number (ID) that is stored together with the final plane parameters (a_0, a_1, a_2) into a database. Figures 4 - 6 show an example of laserscanning data of a building and the roof planes extracted by this approach.

3.2 Determination of size, slope and exposition

The results of the preceding extraction process are used to determine the relevant features of the roof planes. The *size* A_i of each plane i is directly derived from the number of its pixels. This calculation has to be done separately for each building which is described in section 3.3. The *slope* s_i [%] can be calculated by

$$s_i = \sqrt{(a_1^2 + a_2^2)} \tag{6}$$

where a_1 and a_2 are the according parameters of the adjusted plane (cf. Eq. (1)).

Also the *exposition angle* γ (from North) can be derived directly from these parameters

$$\tan \gamma = \frac{a_1}{a_2} \tag{7}$$

These plane features and the corresponding ID are stored into the same database system for further processing.

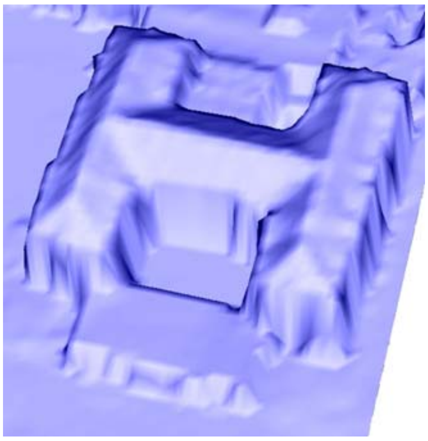

Figure 4. 3D perspective of laserscanning data of a test building.

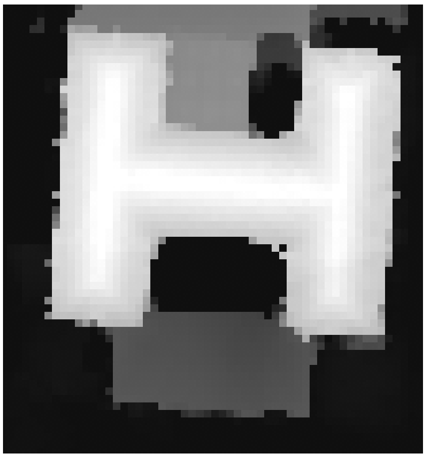

Figure 5. Laserscanning data of the test building (grey-coded).

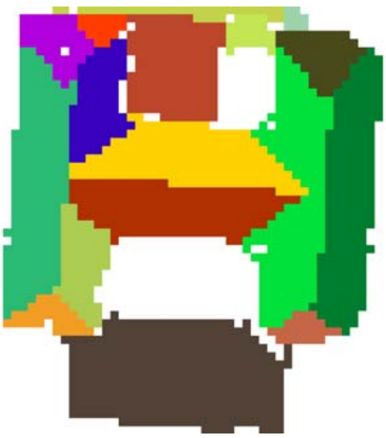

Figure 6. Extracted roof planes for the test building (randomly coloured: same colour – same plane (ID)).

3.3 Assignment of roof planes to individual buildings

In this approach the roof planes are not extracted object-wise, i.e. for individual houses, but for the whole data set in one process. The reason for this is that in the case of building rows or building blocks with the same heigth and slope of roof planes (cf. Figure 7) more robust and reliable extraction results can be obtained due to significant larger areas. Extracting those planes for single houses the number of participating laser points may be too small in some cases to determine a stable orientation or a plane area at all – especially if additional disturbing objects like dormers, chimneys or antennas exist.

After this extraction process every pixel contains the unique ID number of the plane it belongs to (Figures 6 and 7). By means of the contour polygons these planes inside an individual building can be masked. Now their sizes are determined by the number of pixels of each plane and linked – together with its IDs – to the building code number inside the database.

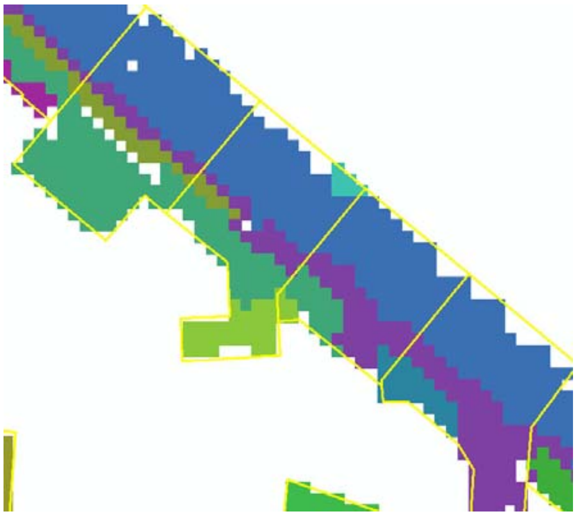

Figure 7. Extracted roof planes (randomly coloured) and the corresponding building contour polygons (cf. Fig. 2 and 3).

3.4 Selection of suitable buildings for photovoltaics

The information about the planes and their sizes of an individual building (section 3.3) has to be linked together now with the extracted plane features (section 3.2) by means of the identical plane IDs. This operation is performed by the GIS and results in a new table containing all data necessary for the subsequent selection process. Table 1 shows an excerpt of such a sample for test area ‘Karlsruhe’.

The selection of suitable roof planes – and therefore, of favourable buildings – for photovoltaics depends on user-defined feature values that have to be based on physical conditions. Dependent on specific regional characteristics (energy supply infrastructure, settlement density, mean sunshine durations etc.) limitations have to be defined for minimum size as well as minimum and maximum acceptable slope and exposition.

Building code number	plane ID	size [m²]	slope [%]	exposition [°]
…	…	…	...	...
16594	729	8	80,9	216,0
	248	72	76,1	40,9
	276	61	74,2	218,8
16595	276	48	74,2	218,8
	248	63	76,1	40,9
...	...	...	...	...

Table 1. Excerpt of the database system (table) containing the necessary data (building code number, plane IDs, size, slope, exposition).

4. PRACTICAL APPLICATION

The method described in section 3 was applied to an urban test area of about 4 km x 2 km in the city of Karlsruhe. This area that covers mainly building rows and blocks as well as complex architectural structures, was chosen to prove the capabilities but also the limitations of this approach. In a first step of quality assessment the obtained results were controlled visually by means of an inspection of aerial images, city maps and the laser surface model itself. The implemented procedure leads to satisfying results. In most cases the roof planes were extracted correctly – taking a certain generalisation effect of this algorithm into account. Nevertheless, at some roof parts unexpectedly more than one plane was extracted due to a higher elevation variance of the laser points or remaining measurement errors. Therefore, in tendency some more planes had been created by this automated method than a human operator would define (cf. Figure 7).

For selection of roof planes that are favourable for photo-voltaics *ArcGIS* was used. Figure 9 shows the result of the final selection process where suitable roof areas are marked.

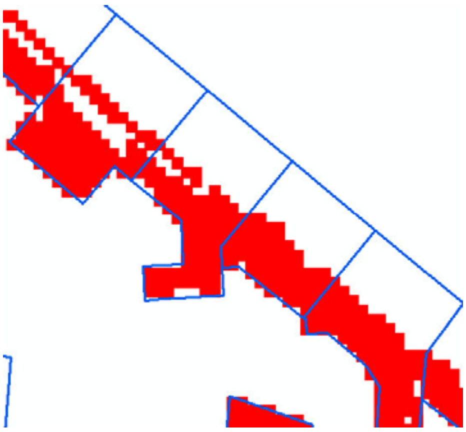

Figure 9. Selected roof planes suitable for photovoltaics (cf. Fig. 7)

It may be also reasonable to differentiate these results in more categories like *preferable / suitable / less suitable / unqualified*. First experiences with this application and this kind of data have featured some specific types of problems. Besides the creation of some additional planes the areas determined by this method may be not usable in total due to disturbing objects not recognised by the automated algorithm. For example windows that are integrated into roof planes (Figure 11) or smaller dormers and chimneys (Figure 12) can of course not be used for a photovoltaic installation. Another problem is the extremely wide range of real building and roof structures that cannot be approximated by planes without certain deviations (Figure 13).

Figure 11. Problematic window integrated in the roof plane (aerial image)

Figure 12. Problematic disturbing objects (dormers, windows, chimneys, antennas) (aerial image)

Figure 13. Complex roof structures (aerial image)

5. CONCLUSION

In this paper an approach to determine and select suitable roof areas for photovoltaics is presented. Applying it to a test area in urban environment satisfying results are obtained. Nevertheless, some types of problems can be observed. In the case of buildings that are modelled by too many planes an additional investigation has to be carried out. It has to be analysed if neighbouring planes with similar parameter values may be merged or should remain separate areas. Moreover, a quantitative (numerical) quality assessment has to be implemented by means of stereoscopic aerial images. Even if the height accuracy is slightly lower it is sufficient to determine the shape of roof structures for evaluating the number of extracted planes and the derived parameters *size*, *slope* and *exposition*. In the case of skylights and other – in the context of photovoltaics – disturbing objects that are not recognized by the extraction algorithm laser intensity values or additional spectral information (e.g. aerial images (cf. Figures 11 and 12), multispectral scanner data) should be integrated in this analysis.

Another aspect in the future will be a prediction of shadowing effects caused by higher buildings or vegetation in the surrounding of a photovoltaic installation or by the topography (hills, mountains etc.) to estimate a realistic sunshine duration for individual locations. For the first one a detailed 3D city model including vegetation objects is necessary, for the latter one a digital surface model (DSM) would be sufficient. Both data sets can be derived from the same laserscanning measurements (e.g. Baltsavias, 2001; Weidner & Foerstner, 1995; Brenner & Haala, 1998; Stilla et al., 2000; Steinle, 2005; Straub, 2003). Based on these data the GIS can perform an according determination and selection of favourable roof planes.

6. ACKNOWLEDGMENTS

The authors would like to thank the State Institute for Environmental Protection (Baden-Wuerttemberg, Germany) and the State Survey Authority Baden-Wuerttemberg for providing the data for this feasibility study.

7. REFERENCES

Baltsavias, E. P., Gruen, A. & L. van Gool (eds.), 2001. *Automatic Extraction of Man-Made Objects from Aerial and Space Images (III)*. International workshop, 10-15 June, Ascona (Switzerland), Balkema Publishers, Lisse, The Netherlands, ISBN 90 5809 252 6.

Brenner, C. & N. Haala, 1998. Fast Production of Virtual Reality City Models. In: D. Fritsch, M. Englich & M. Sester (eds.), '*GIS -Between Visions and Applications*', proceedings of the ISPRS commission IV symposium, Stuttgart (Germany), *IAPRS*, Vol. 32, part 4, pp. 77-84.

Foerstner, W., 1999. 3D-City Models: Automatic and Semiautomatic Acquisition Methods. In: *Photogrammetric Week 99,* Fritsch & Spiller (eds.), Stuttgart, Germany, pp. 291-303.

Quint, F. & S. Landes, 1996. Colour aerial image segmentation using a Bayesian homogeneity predicate and map knowledge. In: Proceedings of ISPRS conference, Vienna (Austria), 9-19 July 1996, *IAPRS*, Vol. XXXI, Part B3, pp. 663 – 668.

Steinle, E., 2005. *Gebäudemodellierung und -Änderungs-erkennung aus multitemporalen Laserscanningdaten*. Ph.D. thesis, Institute for Photogrammetry and Remote Sensing, University of Karlsruhe (in print).

Stilla, U., Sörgel, U. & K. Jäger, 2000. Generation of 3D-city models and their utilisation in image sequences. In: Proceedings of ISPRS conference, Amsterdam (The Netherlands), July 2000, *IAPRS*, Vol. 33, Part B2, pp. 518-524.

Straub, B., 2003. A Top-Down Operator for the Automatic Extraction of Trees – Concept and Performance Evaluation. In: Maas, H.-G., Vosselman, G. and A. Streilein (eds.), '*3-D reconstruction from airborne laserscanner and InSAR data*', proceedings of the ISPRS working group III/3 workshop, *IAPRS*, Vol. XXXIV, part 3/W13, pp. 34 – 39.

Voegtle, T. & E. Steinle, 2000. 3D Modelling of Buildings using Laser Scanning and Spectral Information. In: Proceedings of ISPRS conference, Amsterdam (The Netherlands), July 2000, *IAPRS*, 33, Part B3, pp. 927-934.

Weidner, U. & W. Foerstner, 1995. Towards automatic building extraction from high resolution digital elevation models. *ISPRS Journal of Photogrammetry and Remote Sensing,* 50(4), pp. 38-49.