

3D MODELLING OF BUILDINGS USING LASER SCANNING AND SPECTRAL INFORMATION

Thomas VÖGTLE, Eberhard STEINLE

University of Karlsruhe, Germany
Institute of Photogrammetry and Remote Sensing
voegtle@ipf.uni-karlsruhe.de
steinle@ipf.uni-karlsruhe.de

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ABSTRACT

In this paper an approach for 3D building modelling based on laser scanning data combined with spectral information is presented. Airborne laser scanners offer a new efficient method for 3D data acquisition (DEMs) in urban environment. However, for automatic building recognition and reconstruction, other 3D objects like vegetation or vehicles have to be excluded from the acquired DEM. Therefore, a strategy for stepwise elimination of areas and objects which are not buildings will be explained. These procedures are based on spectral as well as shape and size parameters. After a separation of the remaining 3D objects as building hypotheses, a generic approach for modelling of building shapes by planes will be described. As results of an intersection process wireframe models are obtained. Finally, first experiences with/on this approach in a test area are presented and the achieved accuracy is discussed.

1 INTRODUCTION

In the recent past, an increasing demand of 3D city models for various purposes has been observed, e.g. for planning, administration, facility management or visualization. At first, traditional methods like photogrammetric image analysis by an operator had been applied for this which was a very extensive and time consuming task. Therefore, semi-automatic and automatic approaches based on digital image processing were investigated, e.g. (Grün & Baltsavias, 1997), (Ebner et al., 1999) and (Weindorf & Vögtle, 1998). However, the results from these methods could not totally satisfy the requirements because they had to cope with a lot of difficulties during extraction of 3D objects from stereo or multiple images. First of all, lots of occlusions caused by high buildings or vegetation occur outside the principle point of the images (especially in urban areas) which disturb or prevent stereoscopic analysis. Also irrelevant details of buildings like dormer windows, balconies or chimneys disturb automatic edge detection and matching in aerial images. Furthermore, in most cases no 3D information can be determined in shadow areas or other unstructured parts of the image (e.g. flat roofs).

One of the latest developments in sensor technology, airborne laser scanning, offers a new efficient data acquisition method for measuring urban objects directly in three dimensions and storing the results digitally which shortens postprocessing time enormously. In most cases, the determination of XYZ co-ordinates is based on pulsed laser scanning, i.e. the measurement of the runtime of a laser pulse which is reflected on the surface of the Earth or objects on it (slant distance). By measuring the exterior orientation of the sensor during flight (by means of differential GPS and INS systems) the resulting 3D co-ordinates of the object points can be calculated (DEM). These sensors provide a high point density (commonly 0.5 to 10 points per square meter) and a suitable point accuracy (up to +/- 0.10m in elevation, +/- 0.20m in position) (Baltsavias, 1999). Additional advantages are low dependency on weather and light conditions, few occlusions and point measurements in unstructured areas.

2 OBJECTIVES

In the following an approach for 3D modelling of buildings will be presented combining height data of airborne laser scanning with spectral information. As experiences have shown automatic building detection cannot be done with high reliability when based only on elevation data. Therefore, additional spectral information has to be integrated in data

processing. Up to now, aerial colour infrared (CIR) images are used for this but newest developments aim at using additional multispectral scanner. In future, the integration of spectral information by registering the intensity values of the laser impulses themselves is planned for laser scanner systems. When these systems will be operational, the use of additional data sources will not be necessary.

The strategy of this approach is a stepwise elimination of areas and objects which are not buildings. This can be achieved by spectral, shape and size parameters. In a first step, both the CIR images as well as the elevation data derived from laser scanning have to be preprocessed. The CIR images are geometrically rectified (orthophotos) by means of laser DEM. The subsequent identification of vegetation areas is based on well-known vegetation index NDVI (section 3.1). On the other hand, terrain undulations have to be eliminated from the elevation data, so only 3D objects on this surface remain (section 3.2). In the next step, all vegetation objects are eliminated by superimposition of NDVI image with preprocessed elevation data. The remaining 3D objects are separated from each other and their shape and size analyzed in order to exclude other non-building objects, e.g. vehicles or remaining artifacts (section 3.2). All 3D objects which are left after this preprocessing are regarded as building hypotheses and therefore modelled by planes which are estimated by a special region growing algorithm (section 4.1). The intersection of these planes leads to the resulting contour lines and corner points of each object. These graphical primitives are used to build up a wireframe or surface model (section 4.2).

3 PREPROCESSING

3.1 CIR images

For a subsequent superimposition of CIR images with laser DEM both data have to be related to the same georeference system. While laser scanning data are already geocoded, CIR images have to be rectified to obtain geometrically comparable data sets. Therefore, CIR orthophotos are produced by means of the laser DEM (Figure 1).

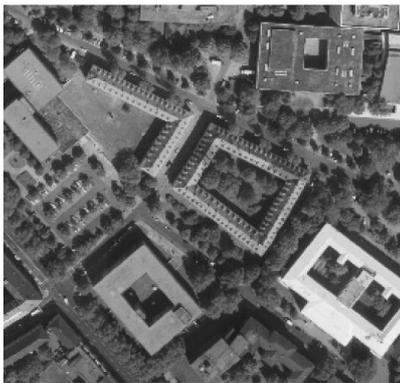


Figure 1: Georeferenced CIR image (orthophoto), subset of test area *Karlsruhe*

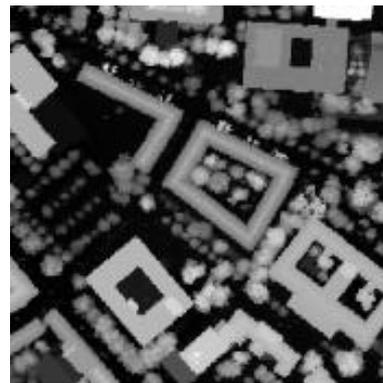


Figure 2: Laser dDEM, terrain reduced (original DEM – DTM)

In the next step vegetation areas are extracted by well-known Normalized Difference Vegetation Index NDVI (Schilling & Vögtle, 1996; Vögtle & Schilling, 1997), although other classification procedures could be used as well.

$$NDVI = \frac{IR - R}{IR + R} \quad (1)$$

IR – reflectance value in the near infrared

R – reflectance value in visible red

The big advantage of this vegetation index is, that it is hardly affected by seasonally changing appearance of the plants in the data sets. A binarization of the NDVI values leads to an image containing only vegetation areas (Figure 3).

In a last step mathematical morphology (Serra, 1982) is used to remove obvious inhomogenities caused by shadow effects and spectral deviations. In this case, a closing and an opening is applied (one dilation, two erosions and finally a dilation) to eliminate small areas consisting of only one pixel and to obtain more homogenous vegetation areas (Figure 4). However, the unfavorable smoothing effects of segment boundaries may cause artifacts in the subsequent vegetation reduction process.



Figure 3: Segmented vegetation areas by means of NDVI

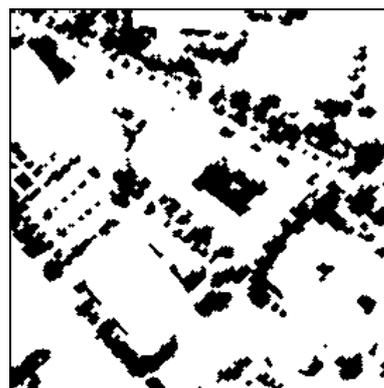


Figure 4: Unified vegetation areas by means of morphological operators

3.2 Laser scanning data

For detection of 3D object on the surface of the Earth, terrain undulations have to be eliminated. Therefore, a special filter has been used for extraction of terrain points (DTM) out of the laser DEM (von Hansen & Vögtle, 1999). After calculating a difference DEM (dDEM) out of laser elevations and this extracted DTM only 3D objects on the surface (e.g. buildings, trees, bushes, cars etc.) remain and all terrain points have a value of about zero. To eliminate the still present vegetation objects now a superimposition of this dDEM (Figure 2) and the vegetation image (Figure 4, sect. 3.1) is carried out and every dDEM element which belongs to a vegetation area is set to ground level (= zero). A detailed comparison of the status before and after this reduction is shown in Fig. Figure 5. Obviously a certain number of artifacts can be observed. These are caused by residual errors in geometrical rectification, smoothing of the boundaries of extracted vegetation areas by morphological operators and shadow regions inside vegetation areas. However, these disturbances can be eliminated in further processing steps using shape, size and plane characteristics.

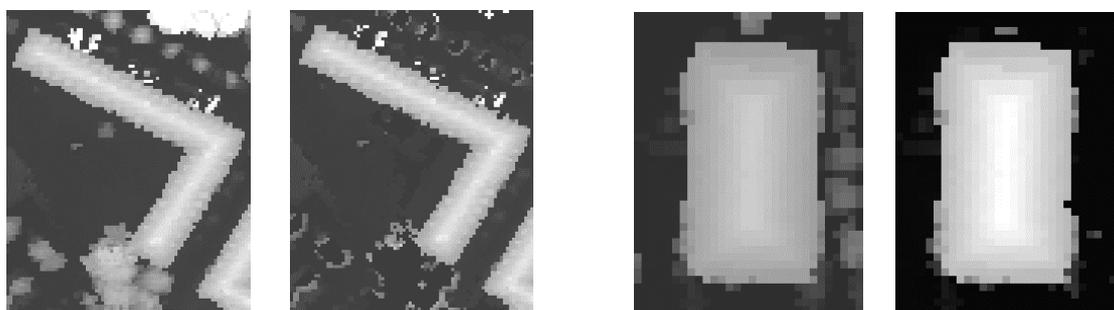


Figure 5: Reduction of vegetation areas; left side: test building 1, right side: test building 2

For separation of individual objects as building hypotheses a region growing algorithm was implemented. This merges neighbouring pixels of dDEM which have only small elevation differences and lie significantly above ground level. The algorithm stops at high gradients which occur normally at the boundary of each 3D object, assigns an individual segment number and therefore determines the membership of each dDEM pixel to a certain object (Figure 6).

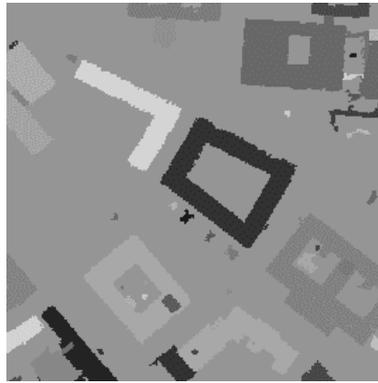


Figure 6: Separated 3D objects as building hypotheses, each containing an individual segment number

Afterwards a vectorization is done by means of triangulation networks. Triangles with small perimeters are selected and merged (Schilling & Vögtle, 1996; Vögtle & Schilling, 1997) which provides 2D contour lines of each segment (Figure 7). The advantage of this method is the closing of interior gaps without affecting (smoothing) the outer contour lines. After reduction of irrelevant points (Figure 7), e.g. by Douglas-Peucker method (Douglas & Peucker, 1973), these contour lines can be analyzed regarding shape and size parameters (e.g. rectangular lines, parallel lines, number of points per area, area etc.). These parameters are used to reduce again the number of non-building objects (e.g. remaining artifacts or vehicles) and to obtain a better preselection of objects as building hypotheses.

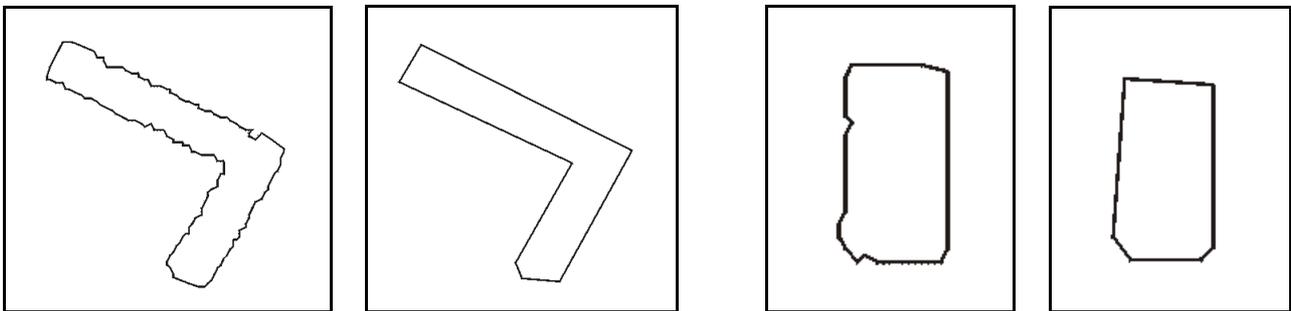


Figure 7: Vectorized contour lines of the objects regarded as building hypotheses (original and Douglas-Peucker filtered); test building 1 (left) and 2 (right)

4 MODELLING OF BUILDINGS

After preprocessing the objects regarded as building hypotheses are modelled geometrically in three dimensions. Today several approaches for modelling of buildings exist. An overview of the current status in this field can be found e.g. in (Förstner, 1999). According to this publication, one of the most important aspects in every strategy is the adopted *building model*, i.e. the representation form of building geometry. There are mainly three different groups of building models: *parametric*, *generic* and *CSG* models.

Using the first representation form, one has to choose a predefined type from a limited set of parametrically described basic house types (e.g. gable or hip roofed ones). The parameters of this basic forms are adjusted to the regarded building. In the generic attempt there is no limitation to special geometries of man-made objects. Here a building is described more generally by a set of connected planes. Therefore, each geometric object consisting of planar surfaces can be reconstructed. CSG method combines so-called building primitives to complex house models, e.g. parametrically described cuboids or prisms. The presented approach belongs to the second group, polyhedral models are used to describe buildings. This implies to estimate roof planes of houses in laser scanner data, combining them by intersection to determine contour lines and corner points of the building. Afterwards the resulting lines and points built up a wire frame model of this object.

4.1 Segmentation of roof planes

In section 3 the extraction of building hypotheses was described. These regions define the areas where roof planes have to be detected. For this purpose a special segmentation algorithm is used which is capable of estimating (oblique) planes in 3D space from laser DEM. The used algorithm is described in detail in (Quint & Landes, 1996). Therefore, only a short summarization will be given. It is a specific *region growing* algorithm with a homogeneity predicate that is based on the *maximum a-posteriori principle*. Originally it was developed for aerial colour images but it has proved to be suitable for a laser DEM as well. In this case the laser DEM has to be stored as an intensity image, where the grey values represent the respective elevations. The homogeneity parameter is the special characteristic of this method. It is based on the assumption that each pixel value can be expressed as

$$I(x_k, y_k) = u f(x_k, y_k) + v Y(x_k, y_k) + w c(x_k, y_k) \quad k=1, \dots, N \quad (2)$$

i.e., a pixel value I at position (x_k, y_k) can be expressed as a combination of three well-defined functions $(f(x_k, y_k), Y(x_k, y_k), c(x_k, y_k))$, each depending on the position of this pixel. They define a so-called image model, i.e. a mathematical description of the grey value distribution. These functions are constant for each individual plane, but differ from plane to plane. The parameters u , v and w are realizations of a random process; they describe a systematic difference of the pixel grey values of an image from the theoretical image model. Beside this, noise has to be taken into account that additionally affect the intensities. Because of these noise effects, it is not possible to verify the homogeneity criteria directly, i.e. the fulfillment of equation (2). This problem is solved by making some assumptions about noise and random process (e.g. normal distribution of noise) and computing a probability value for the fulfillment of this criteria. If the computed probability for the membership of a pixel to a certain region is higher than a defined threshold, the pixel is regarded as belonging to this region.

In principle, an arbitrary image model can be chosen. For this application, a linear approach, an oblique plane in the object space, is used for segmentation of planar parts of the roofs:

$$\begin{aligned} z &= ax + by + c \\ \Rightarrow f(x, y) &= x \quad Y(x, y) = y \quad c(x, y) = 1 \end{aligned} \quad (3)$$

The parameters a , b , c of these planes are estimated by means of this formula during segmentation process and can be used for subsequent processing.

Figure 8 shows some segmentation examples of the DEM regions regarded as building hypotheses. Inside each region planes are estimated representing the shape of the building. Generally, the roof planes are extracted correctly, except the building in Figure 8 (a) where small plane areas at the ends of the house are missing. Also the penthouse in Figure 8 (b) is detected correctly as separate part inside the main roof. In Figure 8 (a) and (c) some small gaps by rejected pixels can be observed. These are caused either by disturbing objects on the roof (e.g. antennas, dormers, chimneys etc.) or by errors in laser measurement, but do not affect the subsequent intersection procedure.

4.2 Determination of contour lines and corner points

After segmentation of roof planes, contour lines and corner points can be derived by intersection of two neighbouring planes and intersection of plane and contour line respectively. This is determined by solving the well-known linear equation system (derived from eq. 3):

$$\begin{aligned} z &= a_1x + b_1y + c_1 \\ z &= a_2x + b_2y + c_2 \end{aligned} \quad (4)$$

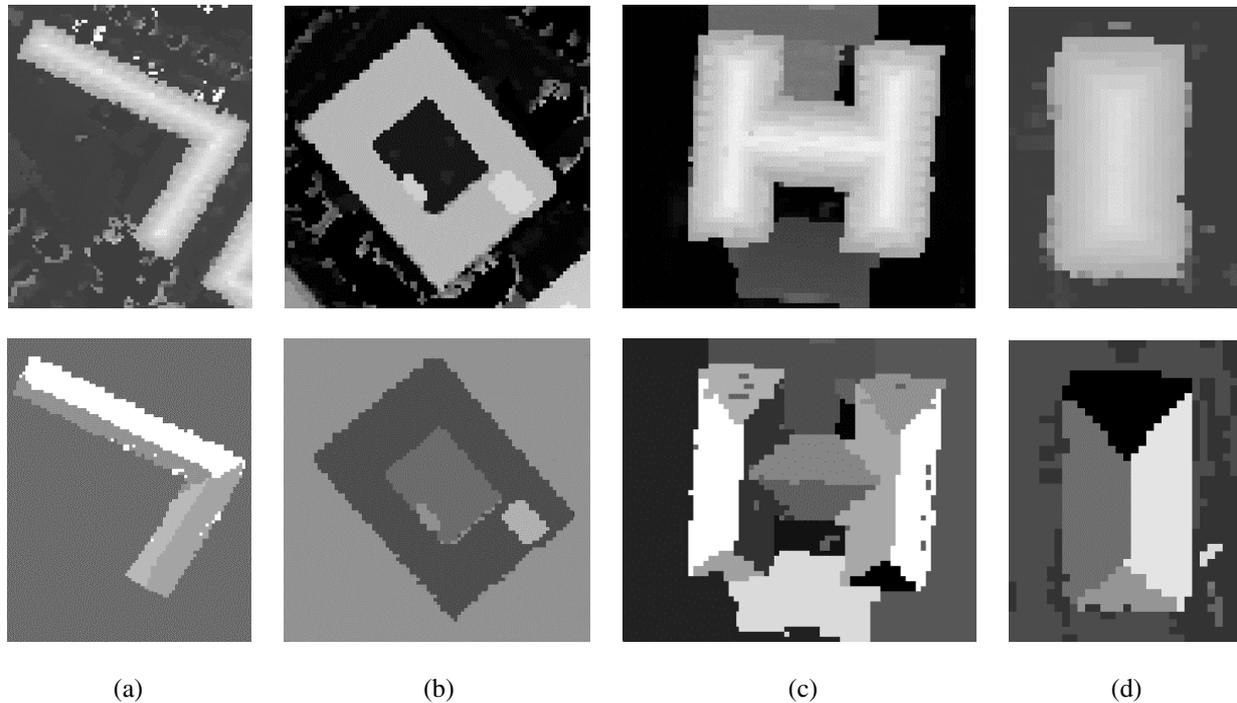


Figure 8: Segmentation of roof planes: (a) L-shaped hip roof, (b) flat roof, (c) complex shape, (d) hip roof; upper row: vegetation reduced laser scanner dDEM of buildings (see section 3.2) lower row: resulting segmentation of roof planes

Before performing this intersection of two neighbouring planes it has to be verified, if there is a significant elevation difference at the edge of these two planes. To avoid disturbances single rejected pixels around this edge (caused by dormers, chimney etc.) are eliminated by a simple majority decision out of the N8 neighbourhood. In the case of significant elevation differences, a vertical plane has to be introduced. The position of these vertical planes can be estimated by an adjustment procedure based on the respective edge gradients in laser DEM. Hence, the intersection process provides two contour lines of the same x, y position but different elevation levels. The resulting contour lines and corner points built up a 3D wire frame model of the building (CAD model). This could be subsequently processed for various purposes, e.g. numerical applications, statistics or visualization.

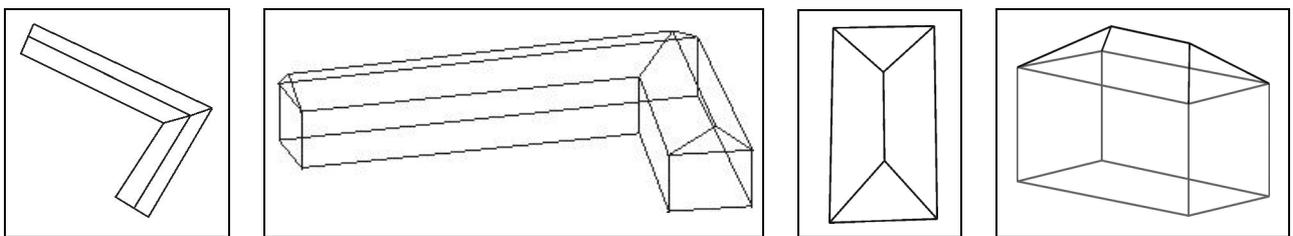


Figure 9: Reconstructed buildings as wireframe models in vertical and perspective view; test building 1 (left side) and 2 (right side), compare Figure 8 (a) and (d)

The results of determination of contour lines and corner points are shown in Figure 9 as wireframe models in vertical as well as in perspective view. It is obvious that the geometry of the buildings has been reconstructed correctly and completely according to the result of the segmentation process (see section 4.1). At corner points where more than three detected planes intersect, ambiguous solutions occur. In this case an adjustment has to be performed regarding the probabilities of each plane. These probabilities have been already been estimated during segmentation process, derived from the membership probability of each pixel to the respective plane. On the other hand, this fact enables the estimation of the interior accuracy of the presented method. First experiences with building modelling in our test areas have resulted in an accuracy of about $\pm 0.2\text{m}$ to 0.3m in position and about $\pm 0.05\text{m}$ to 0.10m in elevation.

A comparison of the resulting wireframe with a manually derived CAD model (accuracy +/- 0.20m) has shown coordinate differences of about +/- 0.2m to 0.9m in position and about +/- 0.2m in elevation, which should be adequate for most applications.

5 CONCLUSIONS

In this paper an approach for recognition and 3D reconstruction of buildings in urban environment is presented. First experiences in our test areas have shown its efficiency concerning accuracy and reliability by using laser scanning elevation data and spectral information. The main advantage of this approach is that the method is not limited to predefined building types like gable or hip roofed ones. The only restriction is the reconstruction of building roofs by planes. Therefore, the overwhelming majority of roof types can be modelled with the exception of conical, cylindrical or other surfaces of higher degree. In these cases a 3D triangulation can be applied for modelling these roof types. Another positive aspect is that no additional data sources like digital city maps or digital cadastral maps have to be provided. Spectral information, as it is used in this approach, is already acquired in today's laser scanning flights by means of video cameras, later on by multispectral scanners or intensity measurement by the laser scanner itself. Nevertheless, further investigations on the building reconstruction without additional spectral information will be carried out at our Institute.

In future, a more sophisticated strategy needs to be developed in order to handle fragmentary acquired building objects in laser dDEM, e.g. caused by eliminated vegetation or disturbing 3D objects on the roof (antennas, wells etc.). Beside this, the algorithm for merging neighbouring or enclosed building parts to form one unique object has to be improved to get suitable CAD objects for further processing (rendering, texture mapping etc.) in 3D city models.

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