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Digital Surface Models for Building Extraction

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Abstract

This paper describes an approach to building extraction using Digital Surface Models (DSM) as input data. The approach consists of building detection and reconstruction using parametric and prismatic building models. The main focus is on the extraction of roof structures, an extension of the previously published work, as first step towards the extraction of polyhedral building descriptions in order to also allow the extraction of complex buildings.

1 Introduction

The increasing need for 3D data of urban areas and its update lead to intense research efforts with the aim to develop automatic or at least semi-automatic tools for the acquisition of such data. Besides digital aerial images Digital Surface Models (DSM, Figure 1[1]) are used as input data. Such DSM contain information about the topographic surface, buildings and other objects. The use of DSM for building extraction is motivated by the fact, that DSM already provide a geometric description of a scene. This description seems to be an excellent intermediate representation for linking the sensor data with knowledge about the objects, giving rise to a number of approaches which exploit DSM for building extraction. Furthermore, the use of DSM allow to apply sensors like airborne laser scanners which have not been used for this purpose. Previously published approaches often use DSM for building detection only. The inherent potential of DSM with respect to building reconstruction was explored only by a few authors, but either restricted to simple building models (Haala 1995) or by using digital images as additional input data (Jaynes et al. 1996). In our approach (c.f. Weidner and Förstner 1995) we focus on the exclusive use of DSM in order to investigate the potential and – of course – limitations of DSM-analysis. Besides parametric building models prismatic models are applied in order to also handle more complex buildings than those given by the parametric models. Of course, these building descriptions still pose a limitation on the complexity of the

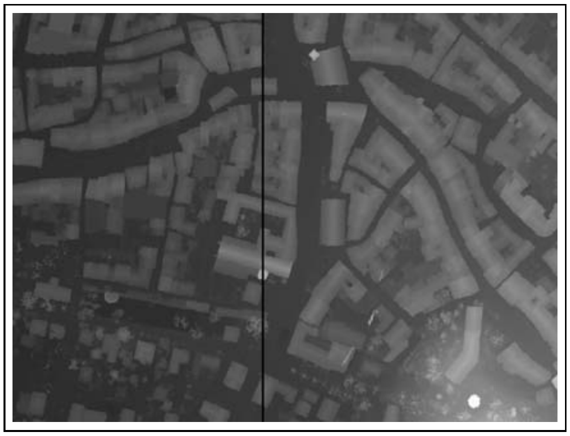

Fig. 1: DSM

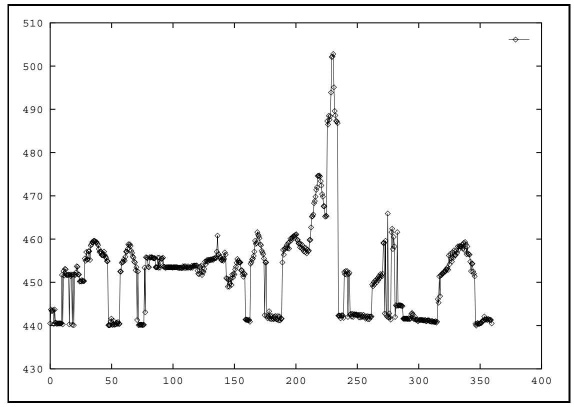

Fig. 2: Section

buildings we can deal with. Therefore, polyhedral models will also be used for building extraction in the future.

In this paper, we will shortly summarize our approach to building detection (Section 2) and reconstruction applying parametric and prismatic building models (Section 3). The reconstruction also includes the selection of the most appropriate of the incorporated building models. The presented results of the model selection for building with complex roof structure (Figure 2) indicate the need of integrating polyhedral models in our approach. The first step towards the extraction of such models is the extraction of roofs, which is the main topic of this contribution (Section 4).

2 Building Detection

The principle idea of our approach to building detection is to compute an approximation of the topographic surface, i.e. to compute a Digital Elevation Model (DEM), to compute the difference between DSM and DEM, i.e. to normalize the DSM, and to segment this normalized DSM. The DEM is computed using mathematical morphology – opening or dual rank filter (c.f. Eckstein and Munkelt 1995). Both techniques can also be applied on a higher level of a DSM-pyramid, if the topographic surface is smooth and the building information is clearly discernible, e.g. minor round offs due to regularization within DSM-generation. Besides these alternatives, a given DEM can also be used. The subsequent segmentation consists of two steps. The first step is a global thresholding of the normalized DSM using a height threshold, which can be fixed considering area specific knowledge about buildings in the scene and the requirements of an application. In the second step, the threshold is locally adapted based on the height information within the initial segments $\tilde{\mathcal{S}}$ and the related bounding boxes without segments $\mathcal{B} \setminus \tilde{\mathcal{S}}$ and the object models. Furthermore, the size of the segments is considered for the selection of valid segments. Again, the threshold can be fixed considering area specific knowledge and user specifications. The result is the refined segmentation $\hat{\mathcal{S}}$.

Other approaches to building detection from DSM are discussed in Baillard et al. 1997.

[1] The DSM RAVENSBURG was provided by TOPOSYS, Ravensburg.

Fig. 3: Variances of normals

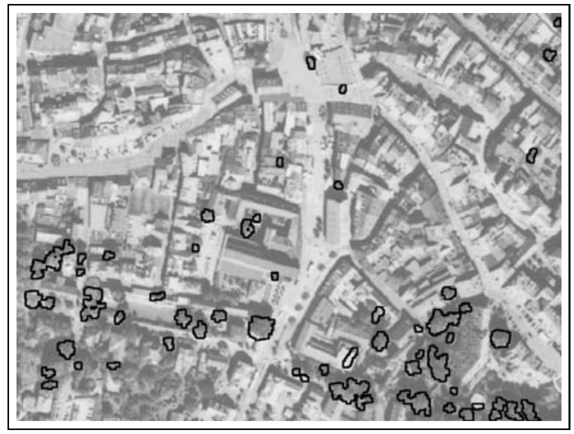

Fig. 4: Detected vegetation areas $\hat{\mathcal{V}}$

These approaches should be compared with each other. The results for the ISPRS *Test on image understanding* (Sester et al. 1996) show no significant differences between the approaches based on mathematical morphology or an analysis of height bins as presented in Haala 1994.

The most severe problem is to distinguish between building and vegetation areas. The size criterion for the selection is not sufficient for larger vegetation areas or vegetation areas close to buildings and probably melted together with these in the DSM. Assuming the geometric description by DSM to be the only input data, criteria to classify vegetation areas must be geometric ones. A possible criterion is the roughness of the surface measured by differential geometric quantities, like gradients or curvatures. We exploit this information by computing step edges and the variance of surface normals as indicator for crease edges (Figure 3), binarizing these data sets, applying morphology in order to derive closed areas, and selecting valid vegetation segments $\hat{\mathcal{V}}$ by size evaluation. Figure 4 displays the detected vegetation areas. These areas can be excluded from the initial segmentation $\tilde{\mathcal{S}}$, thus replacing $\tilde{\mathcal{S}}$ by $\tilde{\mathcal{S}} \setminus \hat{\mathcal{V}}$.

The use of differential geometric properties pose high requirements on the resolution and quality of the data and therefore on the techniques for DSM-generation. Not all vegetation areas are detected, because some are also smooth like the topographic surface or the roof patches. Nevertheless, further investigations seem to be worthwhile, namely to use height information and differential geometry in combination analogously to Brunn et al. 1997. In that approach also other sources of information e.g. texture or colour information from digital images or reflectance information from laser scanners (Hug 1996) can be incorporated.

3 Building Reconstruction by use of Parametric and Prismatic Models

In our previously published work on building reconstruction by DSM-analysis we only used parametric and prismatic building models. These models are subclasses of polyhedral models derived by imposing restrictions on the topology and/or metric. Therefore,

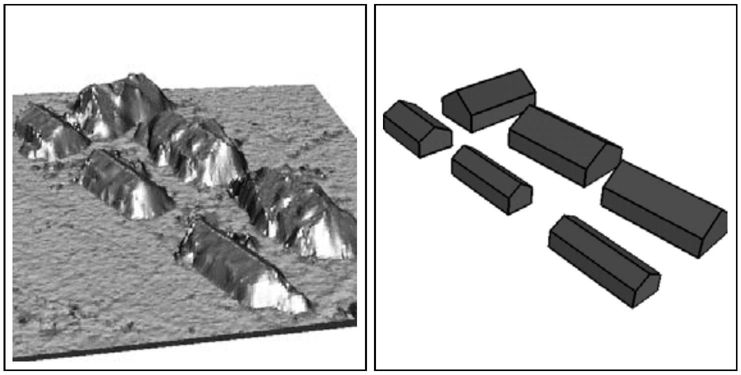

Fig. 5: DSM and reconstructed parametric building models

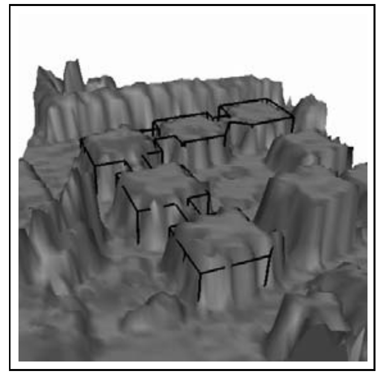

Fig. 6: DSM and reconstructed prismatic building model

the integration of polyhedral models does not change the general framework of our approach, which consists of a reconstruction of the ground plan and the estimation of height parameters. Both steps are performed subsequently for two reasons. The first reason is the complexity of algorithms, the second is the possible use of data from GIS, also allowing a change detection (Weidner 1996). GIS-data mostly provides two-dimensional information about buildings. This information can be easily used, if the extraction of the ground plans and the heights are separated by replacing the information of the segmentation $\hat{\mathcal{S}}$ with the GIS building information $\overline{\mathcal{S}}$.

In case of parametric building models, the ground plan information is derived by applying binary image processing techniques. The height parameters are estimated using a rank operator in order to deal with outliers. The results (Figure 5) are compared to those of other approaches in Sester et al. 1996. The high RMS values for the x, y-coordinates ($\sigma_x = 1.6$ m, $\sigma_y = 1.29$ m) are due to systematic effects within DSM-generation. The RMS-value for the height ($\sigma_z = 0.52$ m) is comparable to the results of other approaches using digital images as input data for building reconstruction. Further details of quantitative evaluation are given in Weidner 1997a.

The reconstruction of prismatic models consists of polygon reconstruction in order to describe the outlines of the buildings and a height analysis analogous to the estimation of height parameters for the parametric building models. The polygon reconstruction makes use of knowledge about regularities of building ground plans, e.g. orthogonality, parallelism, and collinearity. It is based on the *minimum description length* principle (Rissanen 1987). Details are given in Brunn et al. 1995. Figure 6 displays an example of the results.

The next step is the selection of the appropriate model from the set of instantiated building models. The selection is also based on the MDL-principle (Weidner 1997a) and evaluates the description lengths which are necessary to encode the model parameters and the deviations of the models from the data. Some results for the DSM FLAT distributed by ISPRS WGIII/3 are compiled in Table 1. In this example the best available model for the building 3 and 4 are prismatic models, but neither the parametric nor the prismatic building models are really appropriate to describe the roof structure. This is indicated by

Label	1	2	3	4	5	6
Data	81574.40	74850.31	103310.15	106620.74	67028.00	106574.70
FLAT	69626.85	64094.61	105701.00	116757.86	56468.57	97922.75
SYMSL1	68071.77	62786.49	92772.52	97960.89	54349.66	87611.73
SYMSL2	69603.14	64379.33	96029.42	104034.87	57149.01	97694.44
PRISM	69590.48	63939.14	88837.96	90912.13	56940.34	93229.18
DLG	13502.63	12063.82	14472.19	15708.60	12678.34	18962.97
DDL	1518.70	1152.66	3934.56	7048.76	2590.68	5617.45
σ_{DDL}	34.13	32.63	48.44	51.61	32.61	47.09
Model	SYMSL	SYMSL	PRISM	PRISM	SYMSL	SYMSL

Tab. 1: Model selection

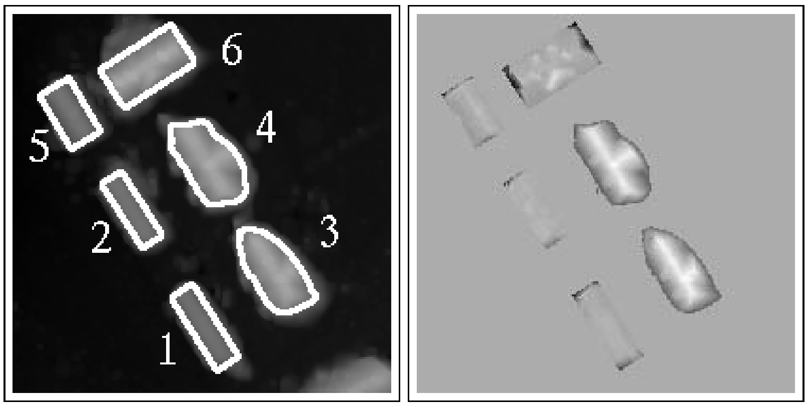

Fig. 7: Labels and height differences DSM - selected model

a visual check of the residuals (Figure 7). In cases of more complex roof structures the description length for models and the residuals DL_M may be larger than the description length needed to describe the input data DL_0. The increase is caused by large residuals, if a complex roof structure is described by a plane with constant height. In order to be able to describe such buildings appropriately polyhedral models have to be integrated.

4 Roof Extraction

The first step towards the extraction of polyhedral models is the extraction of roof planes from the DSM. The approach is related to the feature extraction scheme for digital images described in Förstner 1994. In the following our approach is briefly sketched. Details are given in Weidner 1997b.

The roof extraction is focussed on the detected building segments $\hat{\mathcal{S}}$. The data $\mathcal{D}$ within these segments consists of points which either belong to mutually exclusive homogeneous regions $\mathcal{R} = \{\mathcal{R}_1, \ldots, \mathcal{R}_r\}$, $\mathcal{R}_i \cap \mathcal{R}_j = \emptyset \quad \forall i \neq j$ or to the set $\mathcal{E}$ of non-homogeneous regions, thus $\mathcal{D} = \mathcal{R} \cup \mathcal{E}$. The discontinuities – borders of planar patches – are indicated either by depth changes along the surface normals $\mathbf{n}$ or high curvature, which is related to changes of the surface normals: $\mathcal{E} = \mathcal{E}_d \cup \mathcal{E}_n$. Therefore, the first steps for roof plane detection are the computation of surface normals (Figure 8) and their filtering in order to reduce the influence of noise (Figure 9). The filter follows the scheme of Nagao and Matsuyama 1979. The homogeneity criterion for the selection of the mask is the variance of the surface normals measured by

$$d_{n_l} = \frac{1}{|\mathcal{N}(P_l) - 1|} \sum_{\mathcal{N}(P_l)} \parallel \mathbf{d}_l \parallel \quad \text{with} \quad \mathbf{d} = \mathbf{n} - \overline{\mathbf{n}} \tag{1}$$

where $\overline{\mathbf{n}}$ denotes the mean surface normal and $\mathcal{N}$ the neighbourhood taken into account. The filtered surface normals are used to compute the strength of step edges (Figure 10, left) given by

$$d_{depth} = \max\left(\mathbf{n} \cdot (\mathbf{x}_k - \mathbf{x}_l) | P_k \in \mathcal{N}(P_l)\right) \tag{2}$$

and the surface normals' variances given by (1) indicating crease edges (Figure 11, left), because the scalar product of $\mathbf{d}$ is proportional to the square of the normal curvature (c.f. Besl 1990). Thus similar to Förstner 1994 we distinguish between two types of discontinuities, namely step edges $\mathcal{E}_d$ and crease edges $\mathcal{E}_n$. Both data sets are binarized using e.g. knowledge about the expected value of roof slopes or specifications of required minimal height differences between different roof segments (Figures 10 and 11, right). This binarization delivers the set of detected discontinuities $\hat{\mathcal{E}}$ and finally the detected roof segments $\tilde{\mathcal{R}} = \mathcal{D} \setminus \hat{\mathcal{E}}$ (Figure 12, left). From this set valid roof segments $\hat{\mathcal{R}}$ (Figure 12, right) are selected based on their size, i.e. at least 3 non-collinear points, and their slope. The last criterion is used to reject areas due to round offs within the DSM. Due to the rejection of detected segments $\tilde{\mathcal{R}}$, areas within the building segments which are not covered by valid roof segments $\hat{\mathcal{R}}$ may occur. These areas $\mathcal{R}^*$ can be detected analysing the distance image displayed in Figure 13. The final result of the roof plane detection are the segments and their neighbourhood relations.

The roof plane reconstruction starts from the selected segments. For each planar segment $\hat{\mathcal{R}}_i$ the plane parameters are estimated separately by least squares (Figures 14 and 16). Based on these parameters hypotheses about regularities, e.g. symmetry, i.e. $n_{x1} = -n_{x2}$ and $n_{y1} = -n_{y2}$, or antisymmetry, i.e. $n_{x1} = -n_{y2}$ and $n_{y1} = n_{x2}$, are derived locally between neighbouring segments. (Figure 17 and Table 2). These hypotheses will be integrated in a global robust adjustment and evaluated analogously to the approach for polygon reconstruction of the building outlines. The segments $\mathcal{R}^*$, which may consist of higher order surface areas, are up to now described by planes with constant heights. Further refined reconstruction, e.g. using higher order surfaces, is necessary. For this purpose approaches from range image analysis like Leonardis 1993 will be investigated.

5 Conclusions

In this paper we reported on our work on building extraction using parametric and prismatic building models and presented an approach to roof plane extraction as first step towards the extraction of polyhedral building descriptions from DSM. The detection of buildings is extended by the use of differential geometric properties of the surfaces to

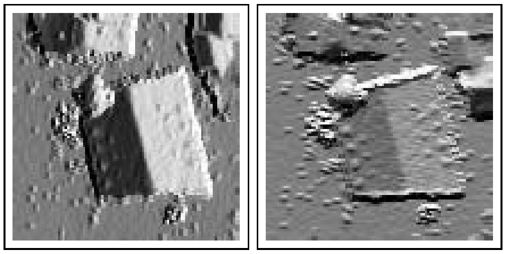

Fig. 8: Surface normals (unfiltered)

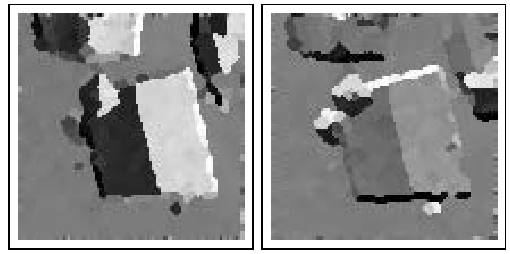

Fig. 9: Surface normals (filtered)

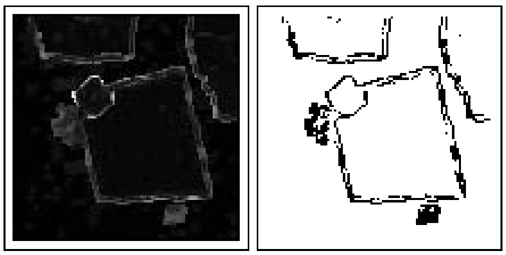

Fig. 10: Step edges

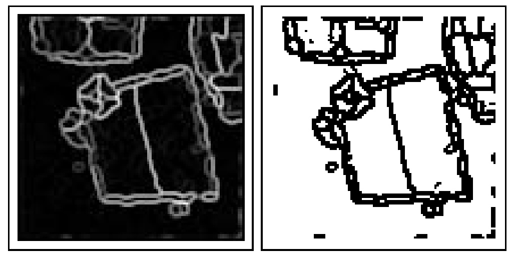

Fig. 11: Crease edges

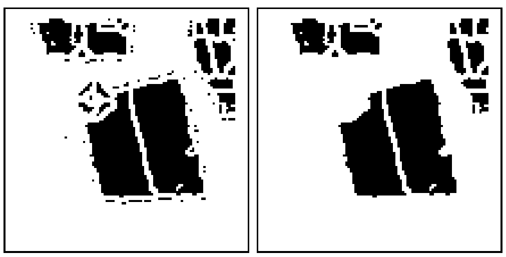

Fig. 12: Detected and selected roof segments

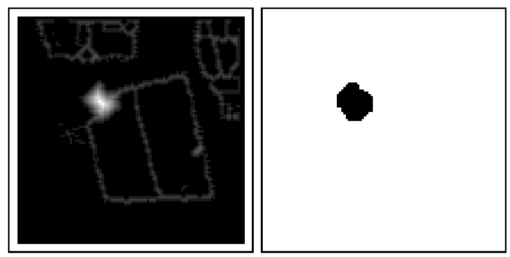

Fig. 13: Non-recovered areas

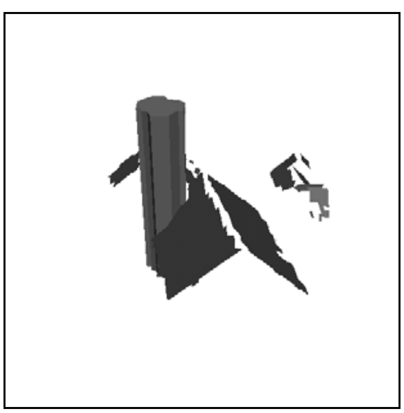

Fig. 14: Reconstructed roof structure

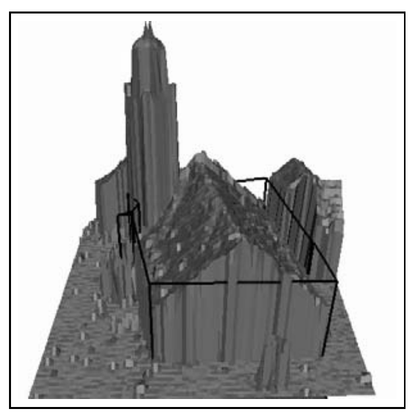

Fig. 15: Data and prismatic model

Fig. 16: Reconstructed roof structures

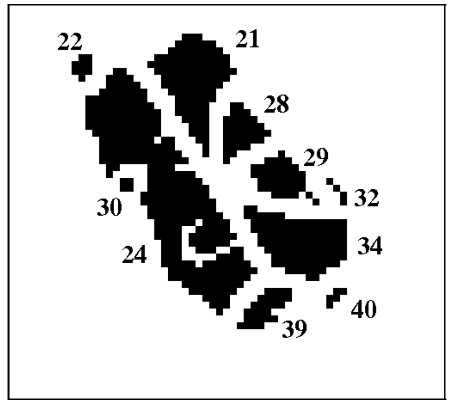

Fig. 17: Example for regularities

	21	22	24	28	29	30	32	34	39	40
21	●		⊙ ⊕	○						
22		●	○							
24	⊙ ⊕	○	●	○		○		⊙ ⊕	○	
28	○		○	●	○					
29				○	●		○	⊖		
30			○			●				
32					○		●	○		
34			⊙ ⊕		⊖		○	●	○	○
39			○					○	●	
40								○		●

● (diagonal) ⊙ slope ⊕ symmetric
○ neighbour ⊖ antisymmetric

Tab. 2: Detected regularities

distinguish between buildings and vegetation areas within the DSM. The use of these properties will be further investigated, namely the combined use of height, gradient, and curvature information in an approach similar to Brunn et al. 1997.

The main focus was on the roof extraction. Up to now the parameters of each plane are estimated separately. Further work will aim at a global robust adjustment including the regularities of roof structures. With respect to this task GIS data may be exploited to derive hypotheses about roof structures analogously to the approaches presented in Haala and Anders 1996 and Pasko and Gruber 1996. In order to derive polyhedral building descriptions the extracted roof planes and the outlines of the buildings given by the polygons have to be combined. For this purpose the type of discontinuities will also be included.

Automatic procedures may fail in recovering the correct information due to the complexity of the task. Therefore, interactive tools for editing the results are necessary. For this purpose our approach to semi-automatic building extraction from digital images will be extended for DSM (Gülch 1997). Different scenarios for interaction will be investigated. Possible scenarios are to use the results of building detection, confirm these interactively (c.f. Heuel and Nevatia 1995), and perform an automatic height analysis or to take the final results of building extraction from DSM and check these results allowing also for interactive computer-aided remeasurement.

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