Unwrapping of Urban Surface Models

Generation of virtual city models using laser altimetry and 2D GIS

Abstract

In this paper we present an approach for the geometric reconstruction of urban areas. It is based on height data from airborne laser scanning and 2D GIS, which provides the ground plan geometry of buildings. Both data sources are used to estimate the type and parameter of basic primitives which in turn are combined to obtain complex building structures. The final output consists of 3D CAD models for the buildings. Using the reconstructed geometry, terrestrial images can be mapped onto building facades to generate virtual city models.

(First paragraph)

The growing demand for detailed city models has stimulated research on efficient 3D data acquisition. Over the past years, it has become evident that the automatic reconstruction of urban scenes is most promising if different types of data, possibly originating from different data sources are combined.

Data sources

Airborne laser scanners have become an important means in the early stage of 3D city model generation. Due to their advantages as an active technique for reliable 3D point determination, these systems provide digital surface models (DSM) of high and homogeneous quality also in urban areas. The test data we use in our work has been acquired by the TopoSys laser scanner with a point density of approximately one point each square meter (Figure 1). The second data source applied in our approach are existing 2D ground plans. This type of information can e.g. be obtained from digitized cadastral maps and provides a reliable and usually sufficiently accurate source of information. The advantages of using existing ground plans are twofold. First, a very detailed 3D building reconstruction can be obtained without the necessity to measure a very dense grid of laser points. Second, data integrity of 2D and 3D GIS can be ensured. Finally, terrestrial images can be used to provide texture for the reconstructed CAD building models, which leads to photo realistic visualizations.

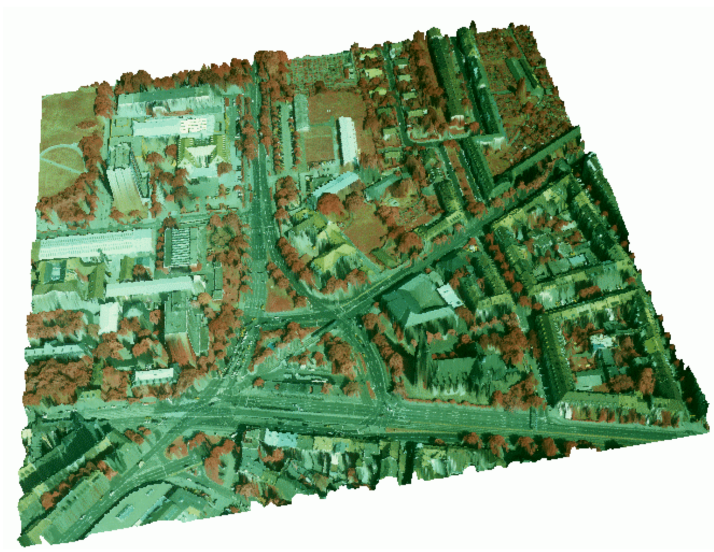

Figure 1: 3D visualization of laser DSM overlaid with CIR ortho image

Representation of buildings

A suitable building model should be general enough to describe objects of different complexity while at the same time imposing geometric constraints during reconstruction. Since most buildings can be described to sufficient detail in terms of general polyhedrons, their boundaries can be represented by a set of planar surfaces and straight lines. Reconstruction constraints are obtained by the assumption that the given ground plan is correct and exactly defines the borders of the roof. In our approach buildings are represented by a combination of one or more basic primitives. Each of the primitives consists of a cuboid element and a roof which can be either a flat, desk, gable or hip roof . This type of representation corresponds to the well-known constructive solid geometry

(CSG) method used in computational geometry. CSG combines simple primitives by means of Boolean set operators (union, intersection, subtraction) in order to obtain complex bodies. Estimating primitive geometry rather than the geometry of complex bodies provides sufficient restrictions to faciliate automatic reconstruction without loosing the possibility to deal with very complex building shapes.

Reconstruction

In the first step buildings are segmented into basic primitives based on their given outlines. The unknown parameters of the generated primitives are determined by a least squares adjustment which minimizes the difference between the DSM obtained from laser scanning and the corresponding roof element of the building. Residuals from the least squares adjustment are also used to select the primitive type.

Figure 2: Ground plan decomposed into rectangles

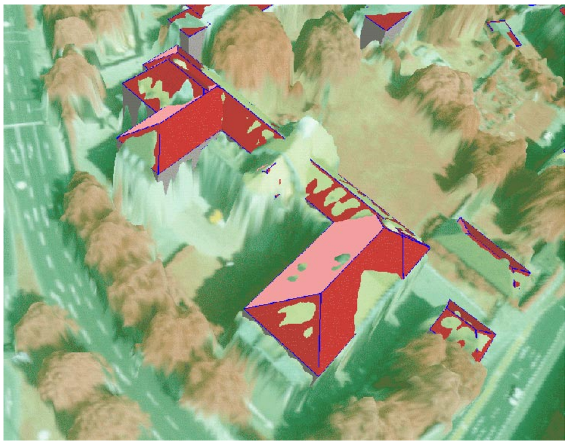

Figure 3: Reconstructed building and DSM

Figure 2 shows an example of an automatic ground plan decomposition. Each rectangle defines the base of one building primitive. Position, orientation and horizontal extension of each cuboid are already defined by the parameters of the rectangle. The remaining unknown parameters are the height of the cuboid, the roof type and the roof slopes. These parameters are estimated by fitting the building primitive to the DSM. Figure 3 shows the reconstructed building and the height data obtained from laser scanning. For visualization the DSM is overlaid with an CIR ortho image. In the final step the union of the set of CSG primitives is calculated in order to obtain a boundary representation of the building which is more adequate for visualization and simulation applications. Figure 4 shows the result of the automatic building reconstruction. The terrain surface was superimposed by a map of scale 1:5000 which was used to digitize the outlines of the buildings.

Figure 4: Reconstructed buildings and map 1: 5000

Manual refinement and semi-automatic reconstruction

The reconstruction is constrained by the assumption that all line segments defined by the ground plan polygon correspond to one wall and to *one* planar roof surface. Also, it is assumed that the ground plan can be decomposed into rectangular primitives. The automatic reconstruction based on those assumptions leads to 3D city models sufficient for many applications. However, a manual refinement can be necessary if a very detailed data capture is required. For buildings reconstructed automatically, parts of the roof can be missing if more than one plane emerges from a single polygon element, or if parts of the building like a bay or small tower are not represented in the ground plan. Hence, for optional refinement of the buildings a graphical user interface (GUI) is provided which allows to interactively modify the geometry of the basic building primitives. Available ground plans and rectangles resulting from the ground plan decomposition can be overlaid simultaneously to the ortho image, map and gray-value representation of the DSM. The GUI allows to define or manipulate the 2D primitive projections, which trigger on-line the reconstruction of building primitives in 3D. Figure 5 shows the original ground plan with two rectangles added interactively. Figure 6 shows the reconstructed building primitives. Elements based on the automatic ground plan decomposition are depicted in blue, the additional primitives resulting from the rectangles generated manually are depicted in red. In case no ground plans are available this interactive mode can also be used for semi-automatic reconstruction.

Figure 5: Original ground plan and additional rectangles

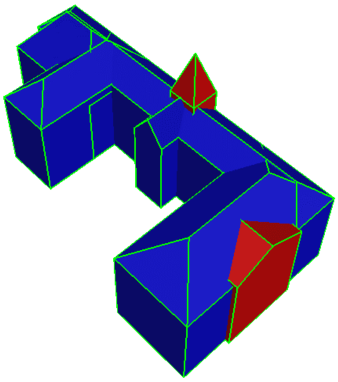

Figure 6: Reconstructed building primitives

Virtual City Models

Detailed and accurate CAD building models are sufficient for many applications including wave propagation simulations. However, if photo realism is to be achieved for visualization purposes, either artificial texture or real world imagery has to be mapped to building facades and roofs. Since real world imagery embodies a representation of object detail, it can even substitute for geometric modeling. To a certain degree non-planar surfaces can be represented by texture mapped planar surfaces without degrading the impression of viewing a 3D scene. Texture mapping from terrestrial images is simplified considerably compared to the standard architectural photogrammetry approach since the vertices of the already reconstructed buildings provide sufficient control point information. In our approach an image section representing a planar building face is first rectified by a projective transformation and then mapped to the corresponding building face. For that purpose at least four tie points between the reconstructed face and the terrestrial image are determined interactively. A visualization generated from the final virtual city model is depicted in Figure 7.

Figure 7: 3D visualization of virtual city model

Summary

Since the combination of 2D ground plans and DSM proved to be very successful the use of this information is strongly recommended for the generation of 3D city models. By integrating the ground plans the consistency between the existing 2D GIS data and the generated 3D data can be guaranteed and detailed reconstructions of buildings can be obtained automatically even for laser data measured at relatively low point densities. Furthermore, the approach can be used in the framework of semi-automatic data acquisition where manual primitive definition from a DSM or ortho image in 2D is used to trigger automatic reconstruction in 3D. In the presented approach the 2D GIS data is used to guide the analysis of the laser data, which means the algorithm has to rely on the ground plans. Further work will have to be done for automatic update of existing data which requires an even closer cooperation between the utilized data sets and algorithms.

Biographies

	Norbert Haala received his diploma in surveying from the University of Stuttgart in 1990. He started as a research associate at the Institute for Photogrammetry, Stuttgart University working in the field of automatic image interpretation and finished his Ph.D. thesis in 1996. From 1995 to 1998 he was the head of the research group "Sensor Integration", since 1998 he is deputy director at the Institute for Photogrammetry and head of the division "Photogrammetry and Remote Sensing".
	Claus Brenner received his diploma in computer science from the University of Stuttgart in 1994. Since then, he has been with the Institute for Photogrammetry, Stuttgart University. His primary interests are in close range photogrammetry and machine vision, range image processing and segmentation, as well as 3D object reconstruction and recognition based on CAD models. Since 1998 he is the head of the "Optical Inspection" research group.

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