

LASER DATA FOR VIRTUAL LANDSCAPE GENERATION

Norbert Haala, Claus Brenner
Institute of Photogrammetry
University of Stuttgart
Germany
Norbert. Haala@ifp.uni-stuttgart.de

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ABSTRACT

Within this article a procedure for the automatic generation of 3D city models is presented. For that purpose existing ground plans provided from a 2D GIS and height data measured by airborne laser scanning are combined. The presented approach can be applied for a fully automatic reconstruction of an urban model, for interactive control and correction of these automatically generated results and for a semi-automatic data capture. The results are 3D CAD models of the buildings. By an optional mapping of terrestrial or aerial images onto the reconstructed facades, virtual city models can be generated.

1 INTRODUCTION

One of the main tasks in photogrammetry is the efficient data capture for the generation of realistic representations of the real world. A great impact on the future demands to these geographic data bases can be expected due to the great success of the World Wide Web. Amongst other things, this success also resulted in a wide spread of international standards for the description of 3D worlds like the Virtual Reality Modeling Language (VRML). Additionally supported by the free availability of VRML-browsers, 3D visualization is now feasible for each standard user. Thus, the spread of applications, which are based on the access and visualization of virtual 3D worlds will increase tremendously. Possible scenarios are tourism information systems, which can help the potential visitor to plan trips as a preview afore his actual journey using virtual reality techniques. Hotel reservation systems can be integrated in order to give the user an impression of the hotel's surrounding in a virtual 3D environment. Due to the increasing power of personal digital assistants (PDA) also systems for a personal navigation are imaginable, where the user's route is not only overlaid to a 2D map, but is presented much more realistic in a 3D virtual model.

All these applications will result in a great demand for the production of virtual city models and landscapes, presuming the availability of tools for efficient data capture. The development of these tools has been in the focus of a number of research activities and has led to a number of automatic and semi-automatic approaches (Gruen, Baltsavias and Henricson, 1997). Even though fully automatic procedures have been applied successfully for a number of individual data sets, it is generally agreed that their employment in a production environment can not be expected in the predictable future. Consequently, research and development has been concentrated to semi-automatic procedures. A second common trend is the integration of multiple data sources in order to make use of different and complementary types of information. In our approach an automatic data collection for virtual landscape generation is enabled by the combination of Digital Surface Models (DSM), which for our purpose is obtained by airborne laser scanning with a 2D GIS.

Despite the high quality of laser DSM the automatic interpretation of this data in order to reconstruct objects like buildings, which are represented in that data set, remains a very pretentious problem. In our approach this interpretation is supported by the additional use of already existing ground plans. Since these groundplans implicitly contain information acquired by a human operator, the procedure can be denominated as semi-automatic approach. On the other hand, if the algorithm has access to the ground plans and the laser DSM, the 3D city models are generated without any further interaction. In that sense the procedure can be denominated as a fully automatic approach.

2 ACQUISITION OF VIRTUAL CITY MODELS

Within the approach the reconstructed buildings are represented by general polyhedrons. This presumes that all buildings can be described by straight lines and plane surfaces. In order to capture these polyhedral building models two major steps have to be performed.

- A 3D measurement, which – in our case - is based on height data provided by airborne laser scanning. Alternatively, 3D points or lines can be derived from stereo imagery.
- A structuring, i.e. the acquisition of topological relations between the measured 3D primitives in order to get a CAD-like representation of the reconstructed objects. This structuring also implies a semantic attribution in order to separate the captured primitives into different object categories. In addition to the separation, a selection of primitives, which are finally used for the description of the respective objects can be necessary.

Frequently both steps are combined in a common process. In the algorithm described by Gülch, Müller and Läbe (1999) basic primitives are used for the representation of the buildings, which are selected and approximately fitted to the image by a human operator. These building primitives, which are also applied in our approach, already define the topological structure of the measured 3D points and lines. In contrast to that in the approach described in this paper both steps are separated and based on different data sets. For the required 3D measurement

the laser DSM is applied, whereas structuring is based on the automatic interpretation of the given ground plans.



Figure 1 DSM from laser scanning with aerial image overlaid

Usually our DSM data is collected by airborne laser scanning with a mean point density of one point per square meter. This type of data can already be used for the generation of realistic visualizations if an aerial image is wrapped over the DSM surface (Figure 1). Nevertheless, this type of data provides only iconic representations, there is no object related information available at this state. This object related information is for example required in order to enable queries on selected buildings or to integrate the data with a 3D GIS. Additionally, if the original DSM is applied for that purpose, the computational burden caused by the large amount of 3D points to be represented prevents the generation of animated visualizations.

In order to derive the required 3D CAD-model for each building, an abstraction and interpretation of the laser data is necessary. This can be solved relatively easy based on human knowledge and interaction, but is very difficult to realize by automatic procedures. Hence, the key idea of our algorithm is to integrate the required human knowledge into the automatic data processing. This can be achieved by applying existing groundplans, which have been collected in advance by a human operator. Since the human knowledge is implicitly contained in these groundplans, an automatic reconstruction is feasible even for very complex buildings. Additionally, compared to approaches for automatic building reconstruction solely based on laser data also a much smaller density of laser footprints is sufficient. In the approach described by Vosselman (1999) seven points per square meter are required, whereas in our approach one point per square meter is sufficient.

In addition to these algorithmic aspects the integrity of 2D and 3D data sets can be guaranteed if the generation of the 3D urban model is based on the analysis of an existing 2D GIS. This also simplifies the common revision of both data sets. Finally, in case there are no existing ground plans available they can be generated before the actual reconstruction by manual digitization of ortho images or maps. This can be performed with relatively small effort since a standard soft- and hardware-configuration is sufficient for this task.

3 AUTOMATIC AND SEMI-AUTOMATIC BUILDING RECONSTRUCTION

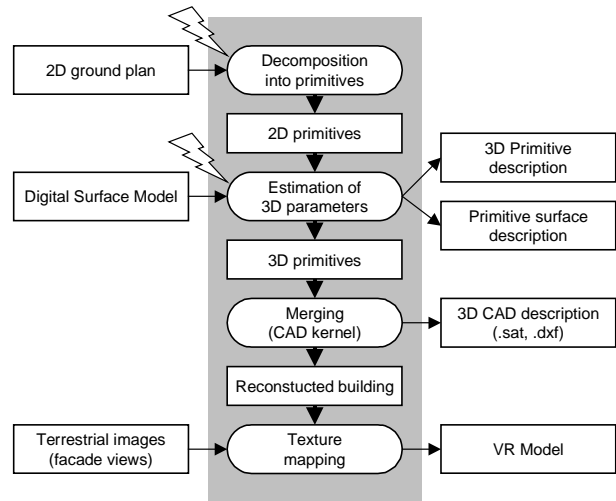


Figure 2: Workflow for the automatic and semi-automatic reconstruction algorithm

Figure 2 sketches the workflow of the reconstruction algorithm. Input data is on the left, output on the right and the flash icon marks the places where automatically derived data can be modified or amended. Processing starts by decomposing the ground plan polygon into 2D primitives (rectangles). Each 2D primitive is the footprint of a corresponding 3D primitive. The location, orientation, and the size of the 2D primitive applies as well for the 3D primitive. What remains to be determined are the parameters of the roof, namely roof type (currently one of flat, gable and hip), height of the building and roof slope. A least squares estimation computes the best fit of the models to the given DSM. When several models are suitable, the one with the smallest residual is selected.



Figure 3: Decomposition of groundplans to rectangles

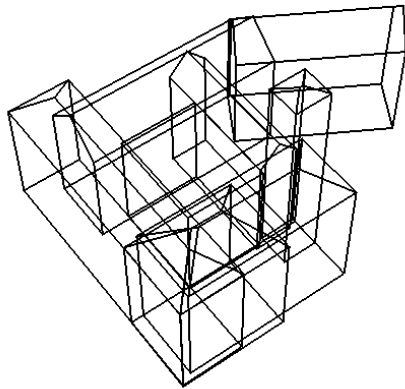


Figure 4: Reconstructed 3D primitives

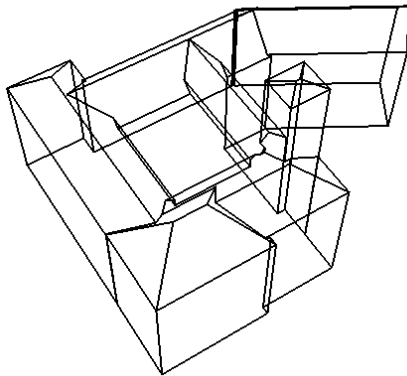


Figure 5: Boundary representation of reconstructed building

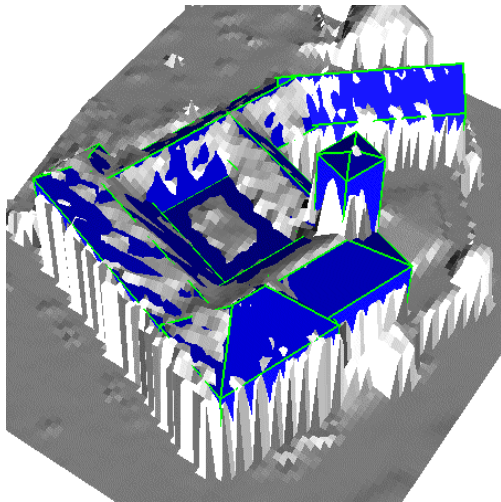


Figure 6: Reconstructed building and DSM

After this step, the individually reconstructed primitives are overlapping 3D solids. They can be output in the form of either a list of solid descriptors or a list of planar faces. Most often it is desirable to find a building description without overlapping parts. As this is a standard CSG problem, a CAD kernel is used to perform the necessary merging (Boolean union) operations. Finally, a non-overlapping building description is obtained, which can be exported and converted into different CAD formats.

The different steps of the algorithm are exemplarily depicted in figures 3 to 6. Figure 3 shows the ground plan of the building after decomposition in different rectangles. Each rectangle triggers the reconstruction of a corresponding primitive (Figure 4). For that purpose roof type, roof height and eaves height are estimated by minimizing the differences between the DSM surface and the 3D primitive. In order to generate a boundary representation, a union of the reconstructed primitives is performed in the final step (Figure 5).

Figure 6 again shows the result of the reconstruction process and the DSM surface used for reconstruction overlaid.

The result of the procedure for a larger area is depicted in Figure 7. This test site is located in the city of Stuttgart. It covers an area of 1.8 km x 2.3 km and contains 5208 buildings, which were reconstructed automatically. For this area the groundplans were provided from an digitization of a 1:500 map or were derived from the original measurements. This digital data set is already available for the complete city of Stuttgart. Almost all buildings could be reconstructed by the automatic procedure with sufficient accuracy. Gross errors in the reconstructed roof shape are only visible for singular buildings. These errors were mainly caused by court yards of buildings, which were not represented properly in the available 2D GIS. Incorrect results can also occur, if parts of the building, like a bay or a dormer window are not represented by the ground plan and therefore can not be reconstructed by the automatic procedure. In this case a manual editing is required in order to correct or refine the result of automatic reconstruction.

For that purpose an interactive tool for the modification of the ground plans is available. The tool allows to define, delete and modify 2D building primitives. Using the same algorithms as those employed in the fully automatic process, three-dimensional primitives are reconstructed instantly when the user modifies the underlying 2D geometry. In order to support the interpretation of the scene by the operator, the editing tool enables the simultaneous display of 2D ground plans and primitives in an arbitrary number of images, like a scanned map, an ortho image or a greyscale-coded DSM. Beside that, a 3D rendered display shows part of the DSM in the vicinity of the selected building and the current 3D building reconstruction. A more detailed description of the complete algorithm can be found in Haala and Brenner (1999).

4 VISUALIZATION

The generation of realistic visualizations as the final goal of our approach presumes the application of image texture. This is also advantageous since the use of natural texture can substitute the geometric modeling of building parts at least to a certain extend. A realistic impression can for example already be achieved if an image of a facade is mapped to the corresponding planar surface of the reconstructed building. In this case a geometric reconstruction of the different windows is no longer required.

The mapping of image texture to the corresponding surfaces of the reconstructed buildings can for example be realized if aerial images are available in addition to the already used DSM and groundplans. After reconstruction the wireframes of the buildings can be projected into the aerial images and the required texture can be extracted and mapped to the corresponding surface patches. This procedure, which was also applied for the generation of Figure 8 is usually sufficient, if image texture is only required for the roofs of the buildings and the terrain surface. In order to provide texture for the facades of

the buildings usually terrestrial imagery is applied. In principle, also for this type of imagery the exterior orientation of the camera be determined in order to extract the corresponding image patches of the visible surfaces. Usually a more straight forward procedure is applied. The corner points of a facade are

measured manually, the corresponding image section representing a planar building face is rectified applying a projective transformation and mapped to the corresponding building face. An exemplary result of this process is visualized in Figure 9.



Figure 7: Result of fully automatic building reconstruction for test site Stuttgart



Figure 8: Visualization of reconstructed buildings with aerial image overlaid



Figure 9: Visualization of buildings after texture mapping of facades.

5 ALTERNATIVE DATA SOURCES

Up to now airborne laser scanning was applied to provide the geometric information for building reconstruction, whereas the image texture was extracted from aerial or terrestrial imagery. Alternatively, the aerial images can also be applied for height data acquisition. This would be advantageous since the same sensor - an airborne camera - can be used to provide the required geometric and radiometric information. Currently, the application of aerial images for DSM generation is mainly hindered by the problems of automatic image matching at occlusions and height discontinuities, which especially occur in built-up areas. These problems can be avoided at least to a certain extent if the applied imagery is captured at a relatively large scale by a normal angle camera.

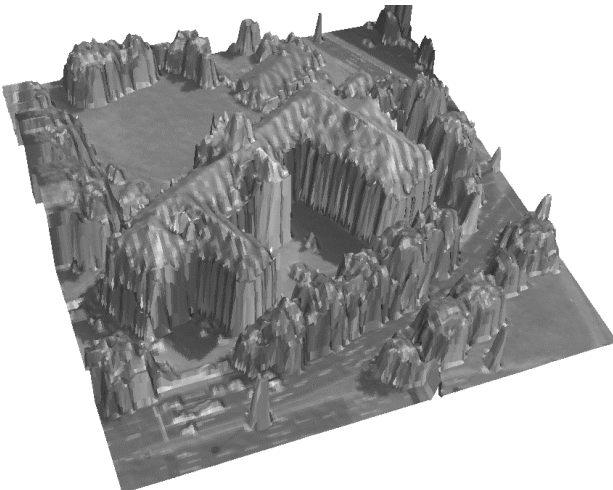


Figure 10: DSM from airborne laser scanning

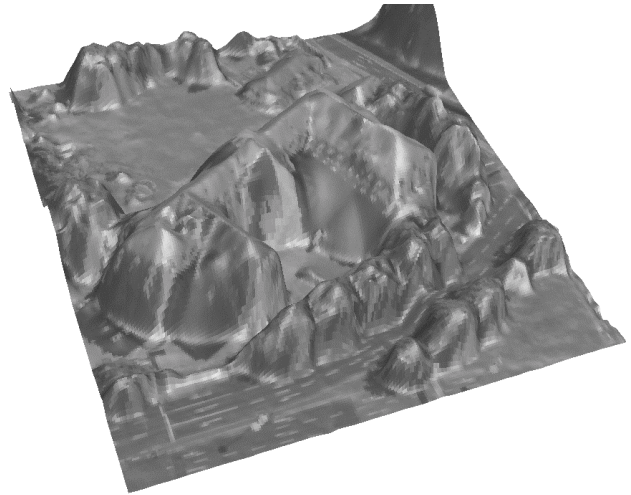


Figure 11: DSM from stereo image matching

An example for the DSM quality, which can be obtained in urban areas is given in Figure 11 and Figure 10. Figure 10 shows a grayvalue representation of height data acquired by laser scanning, Figure 11 gives the corresponding result produced by stereo image matching. In order to generate this DSM the stereo image pair was captured at an image scale of 1:5000 using a aerial camera with focal length of 305 mm. The images were scanned with 15 μm resulting in a ground pixel size of 7.5 cm for each pixel. For DSM generation the standard software tool MATCH-T was applied (Krystek, 1991). In this example the results of airborne laser scanning and stereo image matching can be compared very well since both DSM are collected with a grid with of 1 m. Whereas for the DSM from image matching smooth transitions between roof and terrain surface are visible for some areas, the breaklines are defined more sharply in the DSM from laser scanning. Additionally, details like the small tower are only present in the laser DSM. At the moment the direct height measurement by airborne laser scanners provides DSM data of higher and more homogeneous quality especially in urban areas. Nevertheless a lot of effort has been spent on software development to overcome the deficiencies of stereo image matching in build-up areas. Examples are the integration of knowledge on predefined breaklines or the use of multiple images (Schlüter, 1998). An additional improvement of the derived DSM data can be expected by the increasing quality of original stereo image data if digital aerial cameras are applied (Renouard and Lehmann, 1999). For these reasons, the future development of both techniques for DSM generation concerning accuracy, reliability but also cost effectiveness has to be observed carefully.

6 CONCLUSION

Within the paper an approach for the generation of 3D urban models based on height data from laser scanning and existing ground plans has been presented. The process enables a fully automatic reconstruction of the buildings as well as an interactive refinement of the results provided by the automatic procedure. This is a main advantage of the presented approach, since a fully automatic reconstruction is feasible for large areas, whereas the refinement can be restricted to important parts and can therefore be performed only on demand. Another advantage of using a DSM for virtual landscape generation is the good aptitude of height data for change detection. A change in height must result from a change in surface geometry, whereas a gray

or color value like it is provided from aerial imagery is also influenced by the current illumination or direction of view.

One remaining problem of all approaches aiming on the reconstruction of buildings is the quality control of the reconstructed city model. In our case this is for example to define the need for manual interaction. At the moment, this quality control is mostly based on the visual impression, which is evaluated by a human operator. Of course an automatic measurement, which is also required to compare the result to other approaches should be applied for that purpose. Up to now the great and yet unsolved problems for an objective evaluation of the reconstructed buildings mainly result from the lack of a general model for the object building. These problems are comparable to the great difficulties for tasks aiming on an automatic generalization of buildings in 2D. For 3D applications, where an algorithm has to decide automatically whether certain parts of a building are relevant or not, these difficulties are still larger .

7 LITERATURE

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