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Application of Semi-Automatic Building Acquisition[1]

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Abstract

There is an increasing request for 3D data on city objects of all kinds, confirmed by a recent European wide study on 3D city models. To acquire 3D information in urban areas still is costly, only automated or at least semi-automatic methods appear feasible in the long run to reach the cost-effectiveness, necessary for a broad application. The variety of tasks and available sensor data is very large, which puts high requirements on the design of methods and the flexibility of the acquisition process. This paper discusses the requirements we have encountered so far. We present the design and current status of a semi-automatic system for 3D building acquisition. We demonstrate the potential for handling a variety of applications, using different sensor data under different initial conditions.

1 Introduction

Urban management requires up to date information on all type of city objects, like buildings, traffic networks, public utilities etc. In an OEEPE[2] survey on '3D City Models' producers and users of city object information were interrogated on the current state-of-the art and future needs for 2.5D and 3D information in urban areas. The analysis (Fuchs, 1997) of the returned questionnaires confirmed the usage and the increasing interest and the increasing demands on the availability of 3D city information of all types. Major objects of interest are buildings (in 3D), traffic network (in 3D) and vegetation (in 2.5D and 3D). Major reason for not producing or using 3D data are the high costs, hindering so far a regular request for 3D information. Data sources of the producers are aerial images, map data and classical surveying methods. Aerial range data are only used by some of the producers, but these producers process several 1000 km^2/per year. A trend from raster to vector representations in 2.5D or 3D can be observed.

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[2]The "Organisation Européenne d'Etudes Photogrammétriques Expérimentales"

We are in the process of developing a prototype of a semi-automatic system for 3D building acquisition (Gülch and Müller, 1997); (Gülch, 1996). Existing software is redesigned and adapted. New automation tools are incorporated to provide higher cost effectiveness for initial acquisition, updating and control of 3D building models. We discuss the requirements on such a system, and we describe the design of the system and several projects of different nature that have been performed.

2 Requirements on 3D modeling

Applications, tasks and sensor data put requirements on the design of a system and the modeling process itself.

Applications. We have encountered applications in cartography, city planning, city design, architecture, city development documentation, environmental analysis, telecommunication, and advertising. The great variability and complexity of objects forces any acquisition method to be extremely flexible. Each of those applications defines different tasks to be solved, given specific sensor data. They require different object models, different levels of detail in the modeling process and different output.

Tasks. We can distinguish between *routine projects* and *special projects*. *Routine projects* cover a large area, the conditions are formalized and input and output, like generalization, accuracy and reliability are well specified. In *special projects* the conditions might vary from excellent to problematic. There are the problems of availability of suitable sensor data due to tight time frames as well as the lack of formal descriptions on the quality and type of the anticipated results. We can further distinguish between *simulation/analysis* on one hand side and *visualization/animation* on the other hand side. Simulation puts high requirements on the geometry, like the level of detail and the accuracy of building data, whereas visualization usually puts lower constraints on the geometric quality of the 3D objects. However, in case of integration of texture, especially from close range imagery the conditions change. With unfavorable oblique views, the requirements on the geometric quality of the building model can be extremely high to yield high quality animation results. *Initial acquisition* is often regarded easier than *updating*. We can currently observe projects with coarse initial acquisition, with lower costs right now, but in several cases it occurred not to be sufficient in the long run and thus eventually requires a complete re-acquisition. For the *validation of results* the possibility of viewing and editing complete models instead of point type comparison is necessary. The tool should be in addition flexible enough to handle different data sources to check other methods as well.

Sensor Data. The range of data available is very large which puts high requirements on the interfaces and the evaluation methods. We have to deal with aerial- and close range imagery and with single-, stereo- or multiple image(s). The images are in b/w, but can be in color as well. We should be able to deal with 2.5D Digital Surface Models and with 2D digital map data for updating purposes.

Software Design. Developing a system for semiautomatic building acquisition is a complex process, that requires constant integration and updating of software modules and user interfaces. It requires a management of complex tasks and objects and of huge amounts of data. It is a long term process, which should make reuse of well established existing modules and allow for full extensibility, i.e. integrating and testing of new developments. Maintenance and portability are of utmost importance for future applications. To facilitate these processes we apply an object-oriented design not only for the data but also for the software involved. The previous procedural system has been redesigned making use of well established modules. The system can now be used as a *Program* or as a *Class library*. In the first case, the operator acquires data and the object oriented design is hidden. In the second case, the 3D modeler can be used as a class library in an external program for new applications. A direct access to the object classes is available.

3 The 3D-modeling tool

The large variety of buildings up to now prevents fully automatic systems to yield successful data interpretation on larger data sets. To reliably perform or complete the 3D reconstruction from sensor data we use semi-automatic procedures, related to early work done at SRI (Quam and Strat, 1991). In cooperation with the Institute of Computer Science III, University of Bonn an early approach (Lang and Schickler, 1993) has been extended using the Constructive Solid Geometry (CSG) for the three-dimensional modeling of complex buildings (Englert and Gülch, 1996). The system has recently been completely redesigned (Gülch and Müller, 1997) and new automation modules have been incorporated.

3.1 The measurement flow

The operator is providing the interpretation step, supported by various automated modules. We must be aware of the fact, that sensor data only provide access to the geometry and the physics of a building, allowing to derive the 3D shape and infer some of the semantics of its parts. The orientation data of the images are supposed to be known. We model buildings (cf. Fig. 1) as a combination of a standard set of volumetric parametric primitives (box, saddle-back-roof, etc.) following the CSG principle. By boolean operations of these primitives very complex building structures can be reconstructed. The operator performs a monocular form and pose adaption of a selected building model in one image and measures (or matches) homologous points in the other image(s) to get the absolute height. The system does not require stereo-viewing and is such suitable also for non-photogrammetrists. No specific photogrammetric hardware is required, like in Analytical Plotters. The modeling process results in a CSG tree, whose interior nodes contain operations and the leaves contain instantiated primitives and attributes. The CSG structure can be converted to Drawing Interchange File (DXF) format for standard CAD systems. An interface to the Virtual Reality Modeling Language (VRML) links this output to the visualization tools of various platforms and the World Wide Web (WWW).

3.2 Integrated automated modules

There are different information sources on buildings available, distinguishable in type, cost-effectiveness, scale and resolution with images being the major data source. Laser scanners

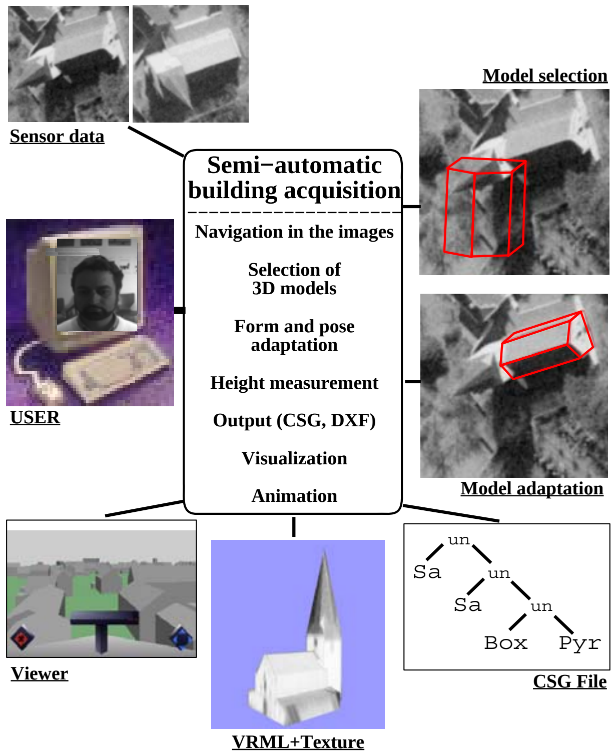

Figure 1: 3D-modeling tool for building acquisition. The user can navigate in complete aerial images. The modeling of selected volumetric CSG primitives is done in monocular mode resulting in a binary tree structure. At least one homologous point has to be measured (matched) to get the absolute height. As output DXF or VRML formats are available combined with texture information for visualization and animation.

are becoming an economical alternative at least for moderate accuracy requirements. We have additional tools at hand and in development (Brunn et al., 1996), that can, through automation, speed up the acquisition process further, if the sensor data is suitable for the task. The following modules have been fully integrated in the newly designed system:

User guidance. The user interface has been newly designed with improved monitoring of the status and improved communication between the user (operator) and the automated modules of the system.

Inheritance of parameters. The inheritance of parameters of the previously acquired primitive(s) allows efficient acquisition in areas with similar building types and reduces the need for homologous point measurements of primitives belonging to the same building in locally flat terrain.

Docking of primitives. Describing a building by the combination of primitives or combined primitives requires a precise "docking" of the primitives. This docking is supported by matching and gluing facilities that are performed automatically with already instantiated primitives.

Triangulation of surface. For visualization purposes where no underlying DTM (Digital Terrain Model) is available, the surface between the buildings is automatically triangulated from the measured ground heights of the buildings.

Texture extraction. For visualization and animation purposes texture is automatically extracted from one or more oriented images and mapped to the extracted 3D faces of the primitives (Gülch and Müller, 1997). If the task does not require the explicit extraction of geometric details, this tool can still provide highly realistic views of the buildings.

Model-image matching. The measurement of homologous points for single primitives can be replaced by an automated matching procedure. The lines of the form and pose adapted parametric building model in one image are compared to automatically extracted line segments in the other images. Robust pose clustering techniques are used to determine the height in 3D (Lang and Schickler, 1993).

Fine-tuning of parameters. In a final fine-tuning step a robust spatial re-section, using all line segments in all images provides an optimal fit of the selected model to the image data (Lang and Schickler, 1993).

General point matching tool. It has been observed that it is necessary to have an additional point matching tool from multiple images available for a) the measurement of single points on the building, b) the measurement of ground points for the determination of the building ground height or the DTM, and c) for the extraction of line type features like road boundaries. A first example on a point matching tool is given in (Müller, 1997). The operator selects one point in one image and the selection of the suitable matching module and the suitable feature- or parameter sets is steered by a classification of the area surrounding the selected point using an automated polymorphic feature extraction (Fuchs and Förstner, 1995).

Height measurement in laser-data. In the OEEPE survey the increasing usage of Digital Surface Models (DSMs) are documented. There does exist an increasing demand on the extraction of vector information from the raster data and on tools to validate and check extracted buildings by non-expert users. In (Weidner, 1997) the current status of automatic building *detection* and *reconstruction* using a DSM as input data is given. First attempts on the extraction of complex roof structures in a high resolution DSM have been reported. However, in very complex city structures the fully automated methods might still fail or give unsatisfying results. To reliably extract the desired building information or to edit automatically derived results, the described semi-automatic system is applied, now using a DSM as input data. Due to the object oriented design, the existing modeler tool could be easily extended by new functionality, keeping the familiar environment and the existing functionality. The 3D primitives for the interactive form and pose adaptation are simply replaced by 2D primitives, defining the ground-plan. The user adapts the 2D primitives to the input data and the height of the roof planes is automatically derived from the DSM. The ground height is taken from the lowest height value(s) in a close neighborhood (cf. also Figures 11- 13). An increase in performance is expected by incorporating the automatically derived results, but has so far been tested only on single examples.

4 Projects

We present results from the acquisition of buildings with the 3D-modeling tool in several projects with different initial conditions and different tasks using different types of sensor data. Not all currently available automated modules have been used in the projects.

4.1 Extended scene - Suburban area OEDEKOVEN

In the scene of about 3 km^2 in the suburban area Oedekoven 5499 primitives have been acquired from two aerial images with an average gross time of 86 seconds/primitive. Figure 2 visualizes a small subset of the acquired buildings. The terrain between the buildings is automatically triangulated from the measured ground heights of the buildings. This test demonstrates the potential of the system for the acquisition of extended complex scenes.

Figure 2: A part of the acquired extensive scene OEDEKOVEN.

4.2 Short training time - Urban area ROSTOCK

A part of the city center of Rostock with complex building structures (cf. Fig. 3) had been acquired in about 15 hours from a stereo pair of aerial images by a non-photogrammetrist after four hours training only. In our experience is not possible with such a short training time on any existing analytical or digital photogrammetric system to get the same output.

4.3 Single image - Downtown FRANKFURT/MAIN

The downtown area of Frankfurt/Main was extracted from one tilted aerial image (Fig. 4), *and* the ground heights of the buildings. The gross time for the extraction of 549 primitives (Fig. 5) was about 17 hours. Texture was automatically extracted from the aerial image and mapped to the 3D faces. A horizontal view (Fig. 6) demonstrates the animation potential of photo-realistic 3D data.

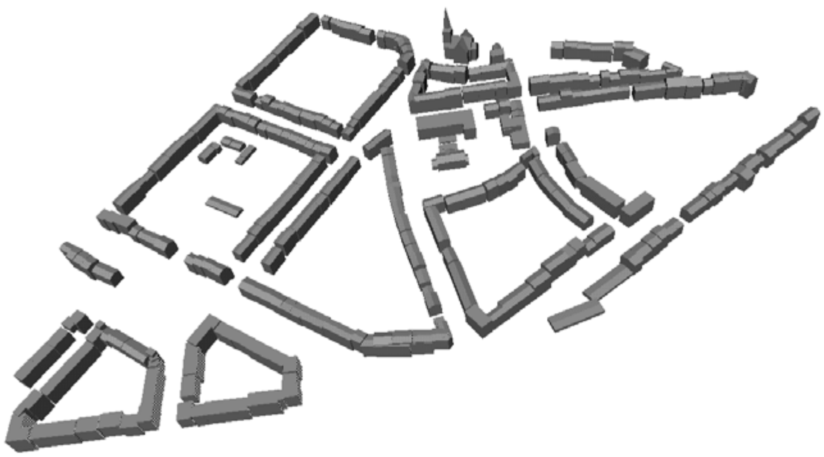

Figure 3: A part of the acquired scene ROSTOCK. Data by Uni Rostock.

4.4 Integration of close range images - NUSSALLEE

The texture extraction from normal case aerial imagery is naturally hampered by the fact, that façades are hidden or cover only small areas in the image. To improve the quality of texture mapping we integrate close range images of the façades (Fig. 7). An automated rectification tool (Bank, 1996) uses automatically detected line segments (Fig. 8) and vanishing point estimation to derive the rotation parameters of the camera and to rectify the highly oblique image (Fig. 9) by assuming a building to have major horizontal and vertical directions. In this first attempt the position of the camera is unknown. The texture is thus mapped to the front of the acquired 3D building model (from two aerial images) by interactive measurement of 3 points. The texture of the roofs and other faces are in this example automatically extracted from two aerial images (Fig. 10).

4.5 Buildings from laser data - City of RAVENSBURG

The 3D-modeling tool has been applied to building extraction in laser data. The groundplans of two building parts have been interactively given in a hill-shaded DSM patch of the city of Ravensburg (Fig. 11). The height of the box is determined by the median of the height values in the box. The roof planes of the saddle-back roof building are estimated by robust adjustment. The ground height is set to the lowest height(s) in the surrounding DSM. In Figure 12 both the DSM and the extracted building (also Fig. 13) is shown.

5 Conclusions

We have presented a prototype system for the efficient semi-automatic acquisition of 3D building information from imagery and DSM data with a high degree of detail in urban and suburban areas. We rely on the human operator to solve the interpretation, but we supply automated tools that efficiently support the interaction. We have found the object-

Figure 4: Large scale aerial image over FRANKFURT. Data by StadtVermA Frankfurt and Digital Affairs Computergrafix.

Figure 6: Automatic texture mapping and horizontal view.

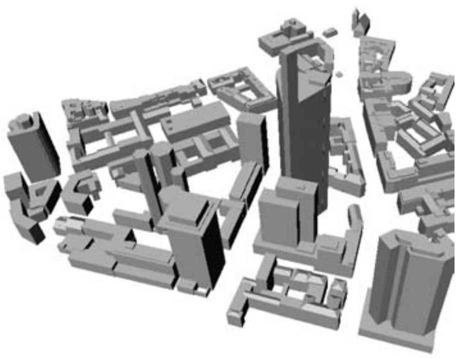

Figure 5: 3D scene FRANKFURT.

oriented design extremely helpful to redesign our system and to integrate new modules. As the system itself can be reused as an object, it is possible to apply the modeler in another context or to extend it by additional functionality. Several other automated modules are in development to further speed up the data acquisition. Links to CAD and Virtual Reality are established. Measurements in and automated texture extraction from close range imagery are in preparation.

The system has been tested on extensive scenes with several thousands of extracted primitives. It has been confirmed that also non-photogrammetrists can use the system after a very short training time, due to the mono-scopic viewing and the developed user interface. In contrast to analytical photogrammetry, the quality of the derived products is increased by automated texture extraction from one or several images. The system is very flexible in handling single images as well as multiple imagery. An empirical comparison to classical photogrammetric methods with respect to efficiency and quality is in preparation. For special topographic applications we can observe similar conditions as in classical close-range applications. The major problem in the special, non-routine projects are the lack of precise definition of acquisition generalization, which is mainly due the interdis-

Figure 7: Close range image taken with KODAK DC25.

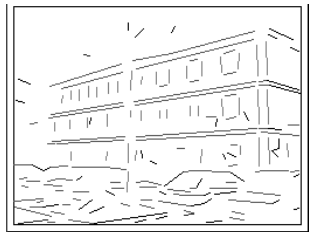

Figure 8: Extracted lines for estimation of vanishing points.

Figure 9: Automatically rectified close range image.

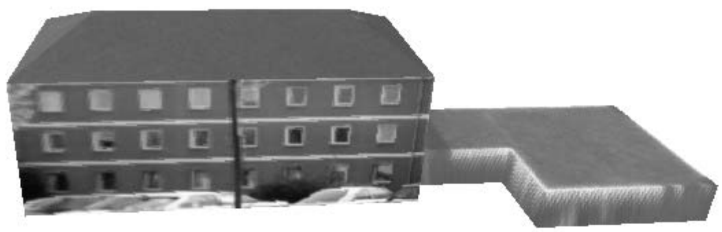

Figure 10: The front of the 3D model of the Institute building has been texture mapped (semi-automatically) using the close range image. The texture of the remaining faces (b/w) is automatically extracted from the aerial images.

ciplinary context. Another problem is the availability and documentation of orientation data of the digital images. A user friendly tool for the determination of the orientation of single and multiple images is a prerequisite. The transfer and conversion of digital image data itself is a tedious work and requires substantial efforts. We can summarize, that the amount of time which is needed for the preparation of the input can be, due to external circumstances, much larger than the acquisition time itself.

Besides an initial acquisition of 3D buildings the updating process as well as the validation and editing of 3D models derived by other methods will be of increasing importance in the future. We regard the developed system a suitable tool to perform these tasks.

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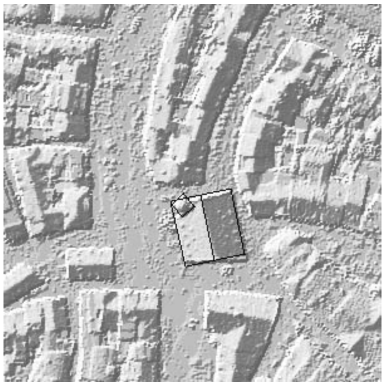

Figure 11: User defined ground-plan in a hill-shaded DSM. Data by TopoSys.

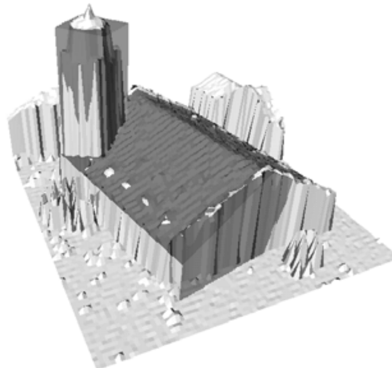

Figure 12: DSM + automatically extracted heights of the tower and the main building.

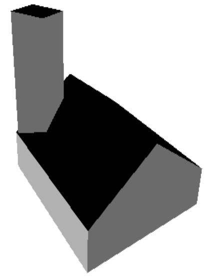

Figure 13: Extracted building.

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