3D-WIREFRAME MODELS AS GROUND CONTROL POINTS FOR THE AUTOMATIC EXTERIOR ORIENTATION

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Commission II, Working Group 5

KEY WORDS: Automation, Orientation, Database, Control point model, Building extraction

ABSTRACT

The bottleneck of today's automation of image orientation is the identification of control points for exterior orientation. A solution for this problem is presented. It is based on 3D-wireframe models of buildings as ground control points. The paper describes the setup of a database of such control points and the use of the data for an automatic exterior orientation.

1 INTRODUCTION

Today we are on the way towards the regular use of digital photogrammetric workstations progressively allowing automation of in principle all steps of image analysis. In nearly every case one needs the orientation parameters of the images. Examples of actually available automatic orientation tasks are the interior orientation, the relative orientation and aerotriangulation. Regarding the different matching tasks of the orientation processes one finds out why solutions for the *exterior orientation* are rare. The following list gives an overview:

- matching between simple 2D-objects and images certainly is the most simple task in case the object can be described by its intensity image. Interior orientation for example can be automized by using classical template matching techniques.
- matching between images and images is of similar simplicity due to the already identical representation. Quite a number of matching techniques are available which may be used for relative orientation or for point transfer in aerial triangulation.
- matching between complex 3D-objects and images is used for image interpretation, e. g. for building detection but also for the important task of control point identification and mensuration necessary for determining the exterior orientation.

Solutions which have been proposed for the automation of the exterior orientation are 1.) the use of signalized control points and 2.) the use of old image templates of natural control points.

Putting the signals on the ground by hand is costly. Signals also have to be larger for automatic procedures than for manual measurements due to the lack of adequate identification procedures which can compensate for varying background. Different templates may be used for different scales of the images. Approach 2), i. e. using image templates, has to cope with many problems such as different illumination, vegetation, scales and perspective of the images used for the setup of the control points and the images which have to be orientated.

We propose to use *3D-control point models* as a solution for the matching task. In most cases the problems mentioned above do not occur. Our module for the automatic exterior orientation uses *sets of 3D-edges* as control point models.

When one sets up *a database of control point models* for this approach, one could in principle use all 3D-objects which are projected in the images as straight lines. But in most cases one wants to use one model for many different areal photographs, which have been taken at different times. Because of this, the 3D-edges have to be *time invariant*. Edges at roads or buildings are such structures. Sometimes the edges of roads, especially of small ones without any markings, vary slightly because of different seasons or weather. Our approach, therefore, uses *3D-wireframe models of buildings* as ground control features, though actually only the 3D-edges of these wireframes are used for the orientation. Using wireframes eases the acquisition of the 3D-structures. Other possibilities are also conceivable.

2 MOTIVATION

The motivation for the development of a module for automatic exterior orientation (AMOR) and the setup of a database of 3D-control point models was the change of the orthophoto production from an analytical to a digital system at the Landesvermessungsamt (State Survey Department) North-Rhine-Westfalia in Bonn.

For nearly 30 years each map sheet of the orthophoto base map 1:5000 was updated at least every 5 years with a new orthophoto from an actual photo flight with an image scale of about 1:12500. With the beginning of this renewal program a database of time invariant control points was established to provide the necessary control points for each spatial resection at the orthophoto projector. These time invariant control points consist of two points on roofs (gables) of a building. In the area of North-Rhine-Westfalia, about 70% of the more than 8000 orthophoto map sheets can be oriented by a spatial resection using these roof points.

For the digital production process we proposed to enhance the control points (2 roof points) to contol point models consisting of wireframe models of the houses or groups of houses. A module for automatic exterior orientation then has at first to detect automatically the control point models in the image, secondly to match the 2D image edges with the corresponding wireframe edges and lastly to compute the spatial resection. The building of the new database is at work at our Institute and this paper reports on this for the first time. Besides the

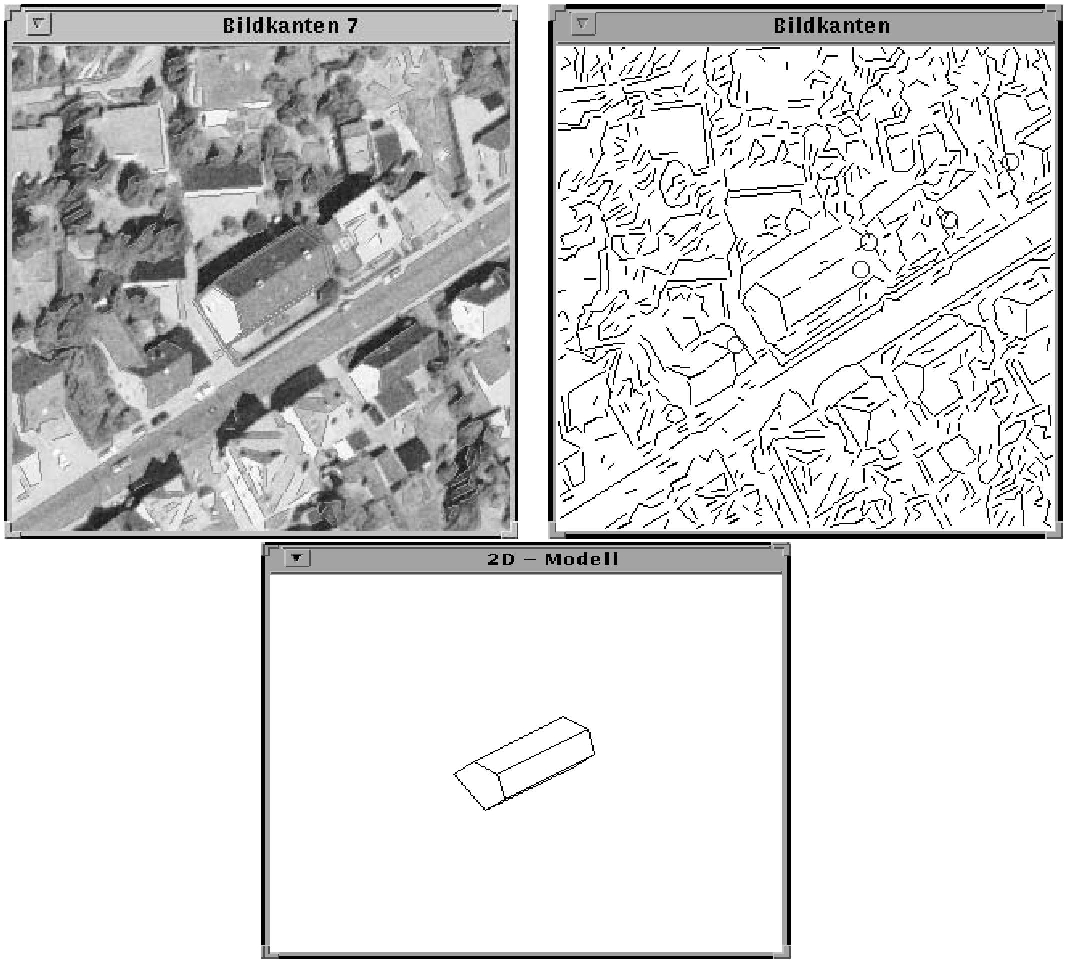

Figure 1: An example of the pose clustering

houses of the old database, additional buildings or groups of houses are chosen for a higher redundancy and robustness of the resection.

3 THE ORIENTATION PROCESS

The module for the automatic exterior orientation (AMOR) was developed by Wolfgang Schickler and consists of the following steps [Schickler, 1994]:

- With the help of approximate orientation values the 3D-edges are projected leading to approximate positions of the 2D-model edges in the image.
- An edge extraction is computed for the parts of the image where the control points should be searched.
- A pose clustering is used to make an approximate search for the 2D-position of the control point models in the image. The model edges are compared to the image edges. In Figure 1 one can see an example of an image part with image edges and the model which should be found. The result of this process is the position where the number and the quality of the correspondences reaches its maximum. At least four control point models must be found.
- The redundancy of the spatial resection is used to detect and correct a false position of control point models.
- A robust spatial resection fits all the models in an optimal way using the correspondence of the 3D model edges to the image edges.
- Finally a selfdiagnosis verifies the result with respect to precision and sensitivity. This enables the automatic procedure to decide whether the determined orientation parameters are acceptable or should be rejected.

Tests with AMOR, using the already measured wireframes, show different criteria which influence the success of the orientation. The following list gives an overview.

- The most important criterion is *the size of the search area* for the models or, in other words, the accuracy of the approximate orientation values given to AMOR. The computation time for the edge extraction and the pose clustering increases significantly when one uses a large search area. When using a small area the probability of finding a control point model becomes higher because there are more non-building edges
- The probability of the success of AMOR could be increased by increasing *the number of control point models*. We use on average 9 models per aerial image.

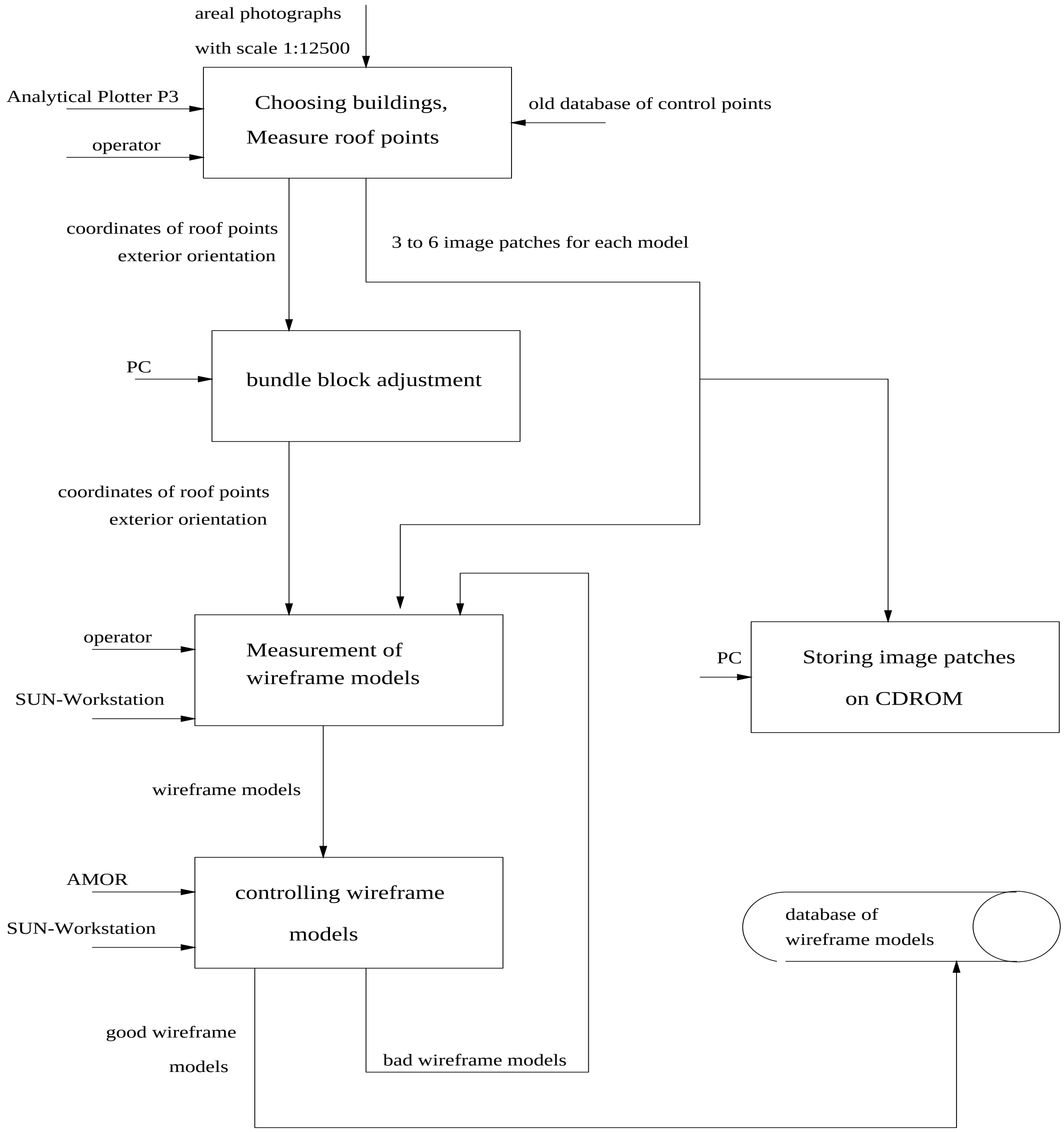

Figure 2: Steps for setting up our database of buildings

- *The quality of the digital images* which should be orientated is also important. Strong texture in homogenes areas for example hinder the search process for the models because there will be many false correspondences of the image edges and the model edges.
- Finally, *the quality of the control point models* influences the accuracy and the success of the automatic exterior orientation.

Concerning the last criterion the results of the tests with AMOR are important for the setup of the database. The following list summarizes the quality aspects of the control point models.

- The model should be *unambiguous* in the search area. It is more difficult to reach this aim in urban than in rural regions. On the other hand, there must be enough buildings to get enough control point models. So built-up areas with building groups which are not close together are optimal. Our tests show that it is possible to orientate images even in urban regions with many identical houses if the search area is small enough.
- *Long model edges* increase the probability of finding the model because in most cases there are not many long image edges which do not belong to the wireframe.
- There should exist *many different directions* of models edges because the primary criterion for the correspondence computed by the pose clustering in AMOR is the angle between the model edge and the image edge. To reach this aim different possibilities are conceivable:
  - One control point model should consist of simple wireframes of different buildings which are not perpendicular or parallel to each other.

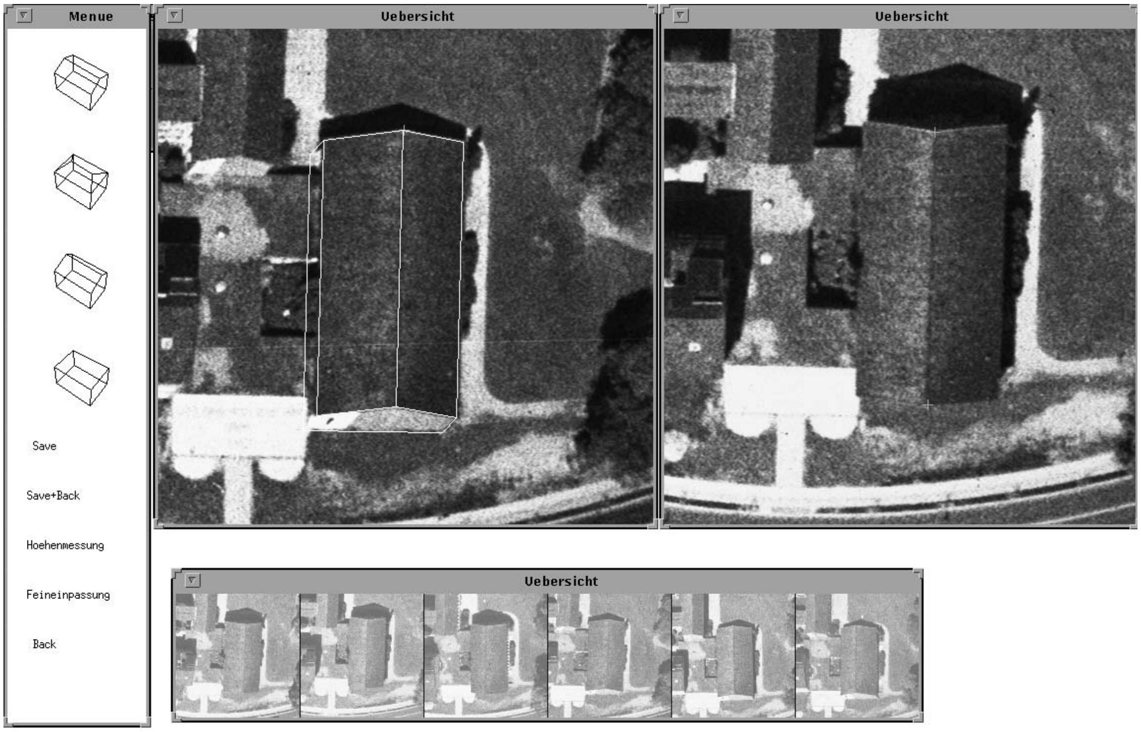

Figure 3: Semiautomatic building extraction

– A union of simple wireframes for a complex building normally results in many edge directions.

– The form of the roof should be taken into account: A hip roof has more directions than a gable roof. A flat roof is the worst case concerning this aspect.

4 THE SETUP OF THE DATABASE

To setup the database of 3D-wireframes we are using image patches (3 to 6) of old aerial photographs with a scale of 1:12 500. Figure 2 gives an overview.

The following remarks should be taken into consideration:

- Step 1: *Choosing buildings.* The choice is done at an analytical plotter P3 equipped with CCD-cameras and is based on the old database of roof points. The old control points are taken over. New ones are also chosen by selecting small building groups. The image coordinates of the roof points are measured. Then image patches covering the buildings are scanned with CCD-cameras. The main results of this process are the image patches with known interior orientation and image coordinates of the roof points. Approximate values are computed for the new points in object space and for the exterior orientation of the aerial images.
- Step 2: *Bundle block adjustment.* The bundle block adjustment is done to achieve good reference exterior orientation values and object coordinates of the roof points. The former measurement is controlled by this step also. The exterior orientation is a requirement for the next step.
- Step 3: *Measurement of the wireframes.* The wireframes are measured in the digital image patches with a program for semiautomatic building extraction [Lang et al., 1995]. Figure 3 shows an example of the acquisition. The interactive process requires the following steps:
  – First the operator chooses one of the image patches of the building. This patch is used for the interaction. It is displayed as the left image on the screen (cf. figure 3).
  – Then he has to move a wireframe model aproximately at the position of the real building. For this purpose he can choose one of the building models of the left menue. The length, height and width are adapted in order to fit the image.
  – The absolute height of the model is calculated automatically by a template matching between the chosen patch and all others.
  – A robust estimation optimizes the correspondence between the image edges in all images simultaneously with the parameters of the wireframe model.
- Step 4: *Controlling wireframes.* Finally all wireframes are being controlled by letting AMOR find the models. Therefore all control points of the area which should be tested have to be already measured. Those models which are not found in many images are adapted again by the semiautomatic building extraction. The operator then tries to improve the model, e.g. by measuring more houses of a building group.

The result of the process is a wireframe model optimally derived from the images. The coordinate data is stored in a database and could be used by AMOR. The image patches are stored on CD-ROM. The patches of control points at the border of a measured block are needed later for attached blocks which also contain these points. The images could be used for other projects as well.

5 MANAGING THE DATABASE

The Institute is setting up a control point model database of the state of North-Rhine-Westfalia for the Survey Department. The size of NRW is about 34000 square km, 70% of this area will be measured. The unmeasured part has no or not enough control points.

Two main problems have to be solved by the management software:

1. The programs have to deal with a large number of coordinate data.
2. Different operation systems (UNIX and MS-DOS) are used in the production process.

The second problem (UNIX and MS-DOS) can be solved either by

- writing interfaces and independent software
  or by
- using a general data model with special management on every system.

The second possibility is chosen because it is more flexible and easier to handle when using the same data model everywhere. From the data access point of view there should be no problem to run an algorithm on different computer systems when using the second solution.

To implement a unique data model, it would be a good idea to use a unique programming language which could easily handle hardware independent and hardware dependent parts. With an object orientated system one can model the specialization problem for different operating system with inheritance. C++ is chosen as the used language because it is available on both systems.

To get an overview of the software system, figure 4 shows the important classes for the management of the data as an object relationship diagram [D.W. Embley, 1992].

The common data access is modeled by the abstract template class *TDataInterface* which offers simple declarations of set-access methods like 'FindFirst()' or 'FindNext()'. On the PC there exist implementations of these declarations as inherited classes for sequential data files and arrays. These classes are also available on the UNIX-system.

At the PC which is connected to the Analytical Plotter P3 only the actual measured block (about 300 aerial images and 750 control point models) has to be managed. But at the SUN-Workstations all the data has to be accessed. This aspect leads us to the first mentioned problem to solve (large number of coordinate data).

In Table 1 one can see the number and size of the data which has to be stored. So much of data could not be managed effectively with simple files or arrays, therefore a database management system should be used. The data types could be easily modeled in a relational system because superkeys already exist and the attributes of the classes are atomic.

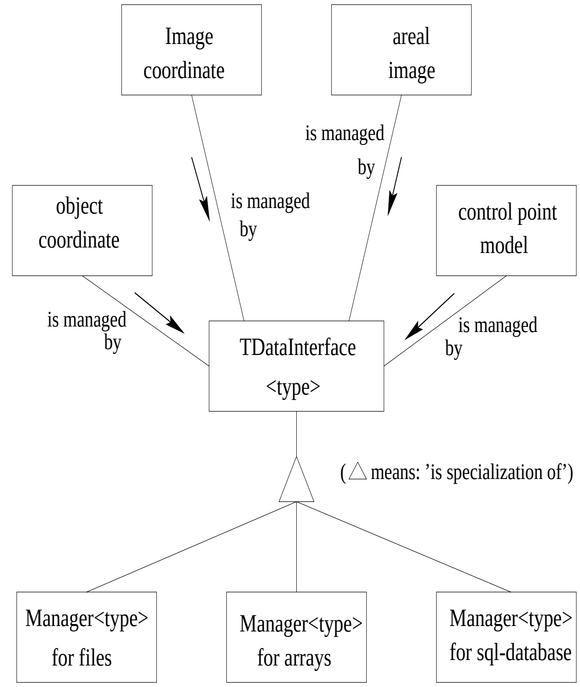

Figure 4: Classes of the management software as an object relationship diagram

Data Type	Number of data	size of data
image coordinates	270 000	13 MByte
object coordinates	60 000	3 MByte
orientation data	16 000	2 MByte
control point models	30 000	30 MByte
image patches	135 000	**33 GByte**

Table 1: Amount of data for North-Rhine-Westfalia

In this project the free available relational database POSTGRES95 is used. POSTGRES95 has an interface for the programming language C which allows the programmer to send SQL statements to the database. For each class with persistent data a table in the database is created. The information could be accessed via a specialization of the class *TDataInterface*. One can also use advanced features of the SQL-language.

The production steps '*Measurement of wireframes*' and '*Controling wireframes*' store and get their data from POSTGRES95. This management allows to gather information about the total already measured area.

6 RESULTS

At the Survey Department North-Rhine-Westfalia the module for the automatic exterior orientation is actually integrated in the orthophoto production process. The Survey Department has chosen a photogrammetric system from LEICA called SOCET SET for their production. AMOR will be run directly after the scanning process or as a batch process at night for several images. The database of the control point models is growing according to the needs of the renewal program.

To get an impression about the success rate of AMOR, we present a test with a block of 195 aerial images which are used for the orthophoto production.

In the test the size of the search area for every control point model was 70x70 meters or 500x500 pixels. The exterior orientation from AMOR was compared to the one of a bundle block adjustment with the roof points as control points. Table 2 shows the result of the selfdiagnosis of AMOR.

AMOR compared to bundle block adjustment	Selfdiagnosis of AMOR	
	correct	incorrect
same result (correct)	88 %	4 %
other result (incorrect)	0 %	8 %

Table 2: Result of a test with AMOR

The expensive error type II, a failed orientation classified as correct by the selfdiagnosis of AMOR has not yet occured. 8% of the images could not be orientated. The success rate of 88 % will vary strongly when one changes the size of the search area.

Because of the need of orientation values in other applications our approach seems to be interesting in other fields, too. It is possible to generalize the ideas of the presented processes because the used 3D-edges as features for the automatic exterior orientation occur in nearly every application.

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