

ATOMI – AUTOMATED RECONSTRUCTION OF TOPOGRAPHIC OBJECTS FROM AERIAL IMAGES USING VECTORIZED MAP INFORMATION

Christoph EIDENBENZ *, Christoph KÄSER *, Emmanuel BALTSAVIAS **

* Swiss Federal Office of Topography
Seftigenstr. 264, CH-3084 Wabern, Switzerland
Tel.: +41-31-963 2311, Fax: +41-31-963 2459, {Christoph.Eidenbenz , Christoph.Kaeser}@lt.admin.ch

** Institute of Geodesy and Photogrammetry,
ETH-Hönggerberg, CH-8093 Zurich, Switzerland
Tel.: +41-1-633 3042, Fax: +41-1-633 1101, manos@geod.baug.ethz.ch

Working Group IC IV/III.2

KEY WORDS: Data fusion, Mapping, Model-based Processing, Feature Extraction, Edge Matching, Object Reconstruction, Roads, Buildings.

ABSTRACT

The project ATOMI is a co-operation between the Federal Office of Topography (L+T) and ETH Zurich. The aim of ATOMI is to update vector data of road centerlines and building roof outlines from 1:25,000 maps, fitting it to the real landscape, improve the planimetric accuracy to 1m and derive height information (one representative height for each building) with 1-2 m accuracy. This update should be achieved by using image analysis techniques developed at ETH Zurich and digital aerial imagery. The whole procedure should be implemented as a stand-alone software package, able to import and export data as used at L+T. It should be quasi operational, fast, and the most important reliable. We do not aim at full automation (ca. 80% completeness is a plausible target). The paper will present in detail the aims, input data, strategy and general methods used in ATOMI. We will also present an overview of the results achieved up to now, and problems faced in building and road reconstruction. More detailed investigations of partial aspects for buildings and roads will be presented in two other papers at this Congress.

1 INTRODUCTION

The last period National Mapping Agencies (NMA), especially in Europe, try to generate digital landscape models that conform to reality and do not include any map generalisation effects. This process allows the integration of additional object classes and information compared to the ones in traditional topographic maps and also inclusion of the 3rd dimension. In addition, the demand for digital data, especially of buildings and roads, for various applications is increasing and the requirements for their accuracy, completeness and up-to-date status are also raised. NMAs have to face these new challenges, on top of production of their usual products, often in shorter revision periods, and with financial and personnel restrictions. To cope with higher product demands, increase the productivity and cut cost and time requirements, automation tools in the production should be employed. As aerial images are a major source of primary data, it is obvious that automated aerial image analysis can lead to significant benefits.

Automated aerial image analysis has been a topic of active research for decades. This includes various aspects like DTM and DSM generation, aerial triangulation, interior and relative orientation, orthoimage generation and mosaicking etc. The last 5 years research has focussed on detection and reconstruction of topographic objects, especially buildings and roads, and generation of 3-D city models. A quite good overview of such research is given in Gruen et al. (1995, 1997), Förstner and Plümer (1997) and in special issues of some journals (ISPRS Journal - April 1998, CVIU - November 1998, PERS - July 1999). However, automated methods fail to provide good quality results and are very slow. Thus, semi-automated methods have been developed and often used successfully in various projects (Gülch et al., 1999; Gruen and Wang, 1998; Lammi, 1998; Halla and Brenner, 1998; Vosselman and Veldhuis, 1999). Some of them have matured and are available as commercial systems. These methods however, require substantial human interaction, in most cases do not make use of a priori information (maps, plans etc.) and are rather focussed on limited areas and object modelling with a high level of detail. New airborne sensors like laser scanners (Lemmens et al., 1997; Hug and Wehr, 1997; Axelsson, 1999; Maas and Vosselman, 1999; Haala and Brenner, 1998; Stilla and Jurkiewicz, 1999; Chilton et al., 1999; Rieger et al., 1999) and to a less degree interferometric SAR (Burkhart et al., 1996; Henderson and

Xia, 1997; Mercer and Gill, 1998; Aero-Sensing Radarsysteme, 2000) or hybrid sensors (Gamba and Houshmand, 1999) have been used for generation of city models and building reconstruction, sometimes with a coarse building modelling. However, these sensors are not widespread, costly, the processing of their data is complicated and not fully automated, are in a relatively early stage of development, plus they usually do not provide the quality and high resolution of aerial imagery, which is necessary for checking and completing the data and other purposes. Digital photogrammetric cameras (e.g. HRSC-A) have also been used for the generation of surface models in cities (Renouard and Lehmann, 1999). However, the problems faced there in automated object reconstruction are similar to those with scanned aerial film imagery.

To ease automation of aerial image analysis a priori information can be used. This includes usually data from maps, GIS and other geodatabases. In addition to existing data, a priori information can include models, constraints about the objects and the scene, rules etc. Thus, the terms knowledge-based, model-based, rule-based etc. have been coined. A particular difficulty in exploiting existing geospatial data for image analysis is that their accuracy and completeness are often not sufficient, or even unknown and almost always inhomogeneous. Thus, mechanisms of estimating and propagating the uncertainty of the input data have to be developed. Examples of approaches that incorporate a priori knowledge for object extraction are given: (a) for buildings in Baillard et al. (1999), Haala and Brenner (1999), Stilla and Jurkiewicz (1999), (b) roads in van Cleynenbreugel et al. (1990), Plietker (1994), de Gunst (1996), Bordes et al. (1997), Vosselman and de Gunst (1997), Prechtel and Bringman (1998), Tönjes and Growe (1998) and (c) other more general objects like landcover classes, urban scenes and sites in Matsuyama and Hwang (1990), Janssen et al. (1990), Solberg et al. (1993), Chellappa et al. (1994), Maître et al. (1995), Stilla (1995), Quint and Sties (1995), Huang and Jensen (1997), Koch et al. (1997), Roux and Maître (1997), Liedtke et al. (1997), Plietker (1997), Quint (1997a, 1997b), Schilling and Vögtle (1997), Tönjes (1997), Zhang (1998), Walter and Fritsch (1998), Walter (1998, 1999), Growe (1999), Kunz (1999), Tönjes et al. (1999), Pakzad et al. (1999). A second clear tendency that aims at easing automation and improving the results is the combination of different input data that provide complimentary, but also redundant, information and cues about the existence, shape, size etc. of an object. Terms like fusion and integration are in vogue, although the theoretical foundations of such procedures are still not well founded, and there are no commonly accepted methods of how they should be performed.

2 AIMS OF ATOMI

The project ATOMI is a co-operation between the Federal Office of Topography (L+T) and ETH Zurich. L+T is responsible for map production in scales smaller than 1:25,000, generation of a nation-wide DTM, generation of digital colour orthoimages, production of digital maps in raster and vector form etc. One of its aims is to produce a digital GIS infrastructure (a Topographic Information System) representing a real landscape model and not a generalised cartographic one. Important objects in this infrastructure are the transportation network and buildings. This data is often required in different applications, especially GIS-based ones but also for visualisation, by public and private organisations. They currently exist or are being generated in vector form by digitisation of the 1:25,000 topographic maps by semi-automatic procedures (called VECTOR25; see more details below). The aim of ATOMI is to update this dataset fitting it to the real landscape, improve the planimetric accuracy to 1m and derive the height of the road centerlines and one representative height for each building. For the buildings roof outline details < 2 m should be ignored. The representative height for each building should be a characteristic one, e.g. first point, first line, top of flat roofs etc. The topology of the existing dataset, with the exception of error corrections, should be maintained.

This update should be achieved by using image analysis techniques to be developed at the Institute of Geodesy and Photogrammetry, ETH Zurich (IGP) and digital aerial imagery. Thereby, IGP makes use of previous experience with other projects for building and road extraction (Henricsson et al., 1996; Henricsson, 1996; Gruen and Li, 1997), which however were rather research oriented, not making use of existing information, and regarding buildings were focussing on large image scales and detailed roof modelling. The whole procedure should be implemented as a stand-alone software package, able to import and export data as used at L+T. It should be quasi operational, fast, and the most important reliable. We do not aim at full automation (ca. 80% completeness is a plausible target), but the "correct" results should be really correct to avoid checking manually the whole dataset. We are envisaging a traffic light system, with high reliability for green, red and yellow, and as high as possible percentage for the "green", whereby an operator should manually check only the yellow, and possibly also red objects. Another important aspect is the use of the current image data as much as possible (1:30,000 image scale, 15 cm focal length, B/W imagery, 25% sidelap), to avoid additional costs. However, it is a topic of the project investigations to find what are the gains with respect to the costs, if colour is used, 30 cm focal length (i.e. 1:15,000 scale), and 60% sidelap for fourwise image overlap. Use of colour is not a big issue, but additional flight strips by using 30 cm focal length or 60% sidelap are of more concern.

3 INPUT DATA

The major input data is VECTOR25. VECTOR25 is generated, using as background the pixel-maps (scanned national maps), with the following software: the semi-automated line-following software VTRAK from LASERSCAN for transportation network and forest limits ; MicroStation from BENTLEY for manual digitisation of areas and single symbols. For automatic extraction of buildings, L+T plans to use the KAMU/AUTOVEC pattern recognition and vectoring software developed at the ETH Zürich (Stengele, 1995; Frischknecht and Kanani, 1997). The transportation network exists over all Switzerland in vector format since the end of 1999. VECTOR25 have an RMS error of ca. 2.5-7.5 m and a maximum one of ca. 12.5 m (based on empirical values), including generalisation. They are topologically correct, but due to their partly automated extraction, some errors might exist. In addition, errors in orientation, size and shape of the objects, esp. the buildings, exist mainly due to generalisation. Figures 1 and 2 show some VECTOR25 data overlaid on the aerial images. Regarding buildings, occurring differences between VECTOR25 and reality include shifts, rotations, more objects in one VECTOR25 buildings, digitisation errors (see top right image) etc. Regarding roads, problems occur in forests and their boundaries, urban areas (occlusions, shadows, trees, cars etc.). The general shape of VECTOR25 is correct (with more problems at intersections and squares), but even in this case vectors may pass on top of buildings, trees etc. Even the spectral properties of the roads may vary (see left and right image on bottom row of Fig. 2). For ATOMI, the VECTOR25 data are delivered in DXF format as polylines, together with any existing class attributes. The objects of VECTOR25 data are digitised for each map sheet into different DXF-layers in a so-called geometric-based form. To exploit the full potential of this vector data over Switzerland, they have to be stored in a GIS. This was the main reason for the establishment of a Geo-Topographical DataBase (GTDB). The system used is ARC/Info with Spatial Data Engine from ESRI using an ORACLE database running under Unix on an IBM platform. VECTOR25 consists at the moment of more than 3 million objects. In GTDB, they are integrated into the so-called semantic model. This model allows searching, e.g. for villages or rivers, and all the related objects are selected and displayed.

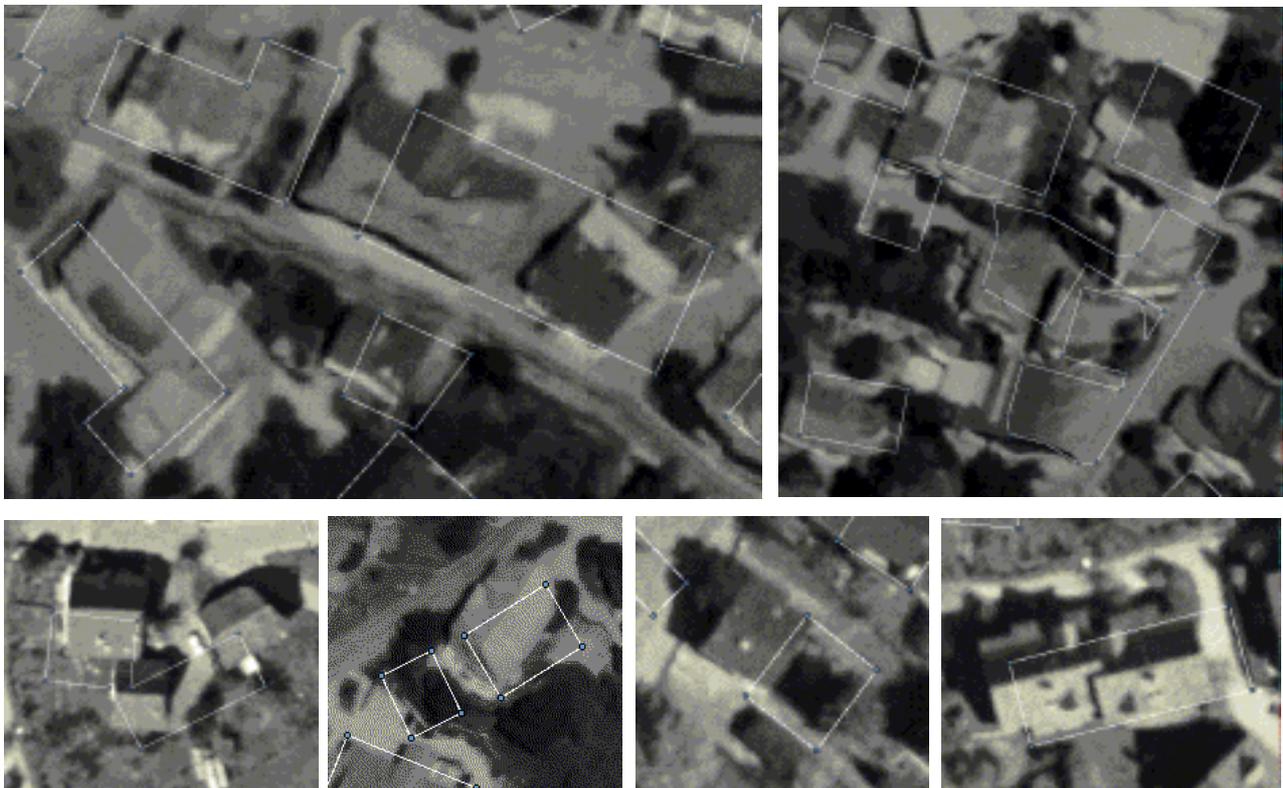


Figure 1. Examples of VECTOR25 data for buildings.

Other input data are: the nation-wide DTM (DHM25) with 25 m grid spacing and an accuracy of 2.5 m in the lowlands and 10 m in the Alps ; the raster map (PIXELMAP) with its 6 different colour layers and the digital images. Other derived data used in the project, are DSMs (1-2 m grid, from 14-28 μm images) and colour orthoimages (0.25 m pixel size), generated with PHODIS OP and TS. Currently, a test dataset in a region with representative topography and landcover for Switzerland is used (Albis, close to Zurich). The colour imagery has scale 1:15,000 (30 cm focal length), 25% sidelap, and was scanned with 14 microns at a Zeiss SCAI scanner. At this region ground truth data (DTM, road

centerlines, building roofs) were measured at a BC3 analytical plotter. The images cover 2x2 blocks in characteristic areas (generally hilly) with forests, agricultural fields, villages, water surfaces, but also modern urban centres with more dense and high buildings.



Figure 2. Examples of VECTOR25 data for roads.

4 GENERAL STRATEGY AND METHODOLOGY

In a first step, we aim at detecting existing objects, while objects that do not exist anymore or new ones will be treated later. Extraction of roads and buildings are treated by two separate researchers, but common input and other derived data, are used by both and at a final stage due to the complementarity of road and building objects the results will be fused. To increase the success rate and the reliability of the results we strongly rely on three aspects:

1. Use and fusion of multiple cues about the object existence and of existing information sources
The information provided by these sources should not be only complementary, but also redundant to account for errors and incomplete results in the low-level image analysis. The basic cues used are DSM blobs, colour, texture, shadows, and edges, while some secondary ones, like motion of vehicles on the roads, signalisation strips, context between buildings and roads etc. will be also used. All these cues have associated relevant attributes.
2. Use of existing knowledge, "rules" and models
They are used to restrict the search space, treat each object subclass differently, check the plausibility of multiple possible hypotheses, and derive reliability criteria. Using the known object class, e.g. highway, 1st class road etc., different possible value ranges for the attributes of these objects and certain rules can be used, e.g. road width, horizontal and vertical curvature of roads, signalisation, no road can cross a highway at the same level etc. The knowledge data base is automatically updated and refined using information gained from image analysis (only from the reliably correct solutions), as well as at the stage of the manual editing and correction of the results at the L+T. The road model includes geometric, radiometric, topological and contextual attributes.
3. Object-oriented approach in multiple object layers
A first, hierarchical, object layer can divide an object class, e.g. transportation network, to various subclasses, e.g. road classes, railway lines, bridges, pathways etc. A second object layer can divide the objects in subclasses according to the landcover and terrain relief, since these factors influence considerably the ability of object reconstruction. E.g. roads will be divided in: inside forest, at forest border, open rural areas, urban areas (and possibly city centres), while use of the terrain relief can be used in determining the plausibility of some object parameters like horizontal and vertical curvature etc. Each subclass of the above two layers will have appropriate

attributes, a respective knowledge/rule database, and processing methods. The processing will proceed from the easiest subclasses to the most difficult ones.

5 SOME RESULTS

5.1 Buildings

More details on this part of the project are given in Niederöst (2000). Various cues are used for building detection. Niederöst first starts from approximations from VECTOR25, or extracted DSM blobs or a multispectral classification (unsupervised K-means classification using 5 information channels). The two last approximations allow detection of new buildings, which do not exist in VECTOR25. DSM blobs can be derived with or without use of the DHM25. The vector approximation is refined sequentially by a shift, rotation and scaling using scores of all possible solutions within a search window, defined by the maximum possible error. Different information channels are involved in the computation of these matching scores. At the end each solution's reliability is computed using the traffic light principle. First test results from comparison to ground truth showed a detection of 89% of the buildings in the image.

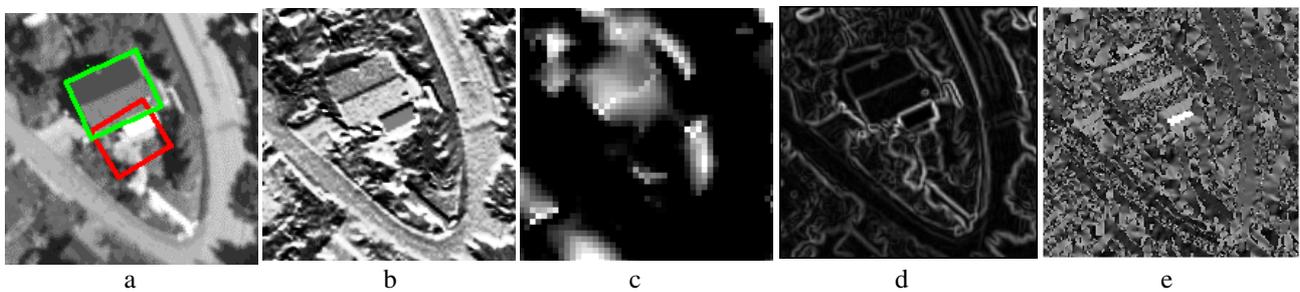


Figure 3. (a) in red the VECTOR 25 approximation, in green the fit of VECTOR25 to the image data; (b)-(e) various cues used in object detection: "artificiality" (factor that separates better man-made objects from natural ones), DSM blobs, edge gradient magnitude, edge orientation.



Figure 4. Reconstructed buildings. The colours green (darker) and yellow (lighter) indicate different degree of reliability. Green buildings were accepted automatically, yellow after manual inspection (but no editing).

5.2 Roads

More details on this project part are given in Zhang and Baltsavias (2000). In a first step of road reconstruction, we aim at detecting existing roads, while roads that do not exist anymore or new ones will be treated later. We first concentrate on roads, ignoring other transportation network objects like railway lines, mountain paths etc. In contrast to other approaches for road extraction, the proposed approach uses multiple cues about the object existence, employs existing knowledge, rules and models, and treats each road subclass differently to increase success rate and reliability of the results.

The initial knowledge database is established by the information extracted from existing geographic data and road design rules. This offers a geometric, topological and contextual description of road network in the scene. The database is automatically updated and refined using information gained from image analysis. Colour cues, expressed in the form of colour region attributes, are also used to support stereo matching and improve the performance of 2D and 3D grouping when combined with geometric cues. Since neither 2D nor 3D procedures alone are sufficient to solve the problem of road extraction, we propose to extract the road network with the mutual interaction of 2D and 3D procedures. Hence, the main steps of road extraction are: building-up of the knowledge base for each road segment in VECTOR25, finding 3D straight lines in a search region defined by the VECTOR25 data, classification of image patches, extraction of other cues, combination of various cues guided by the knowledge database to find plausible groups of road edges for each VECTOR25 road segment and refinement and update of the knowledge database. The general strategy is shown in Fig. 5. Fig. 6 shows more details of the results of image processing and derivation of subclass vector attributes.

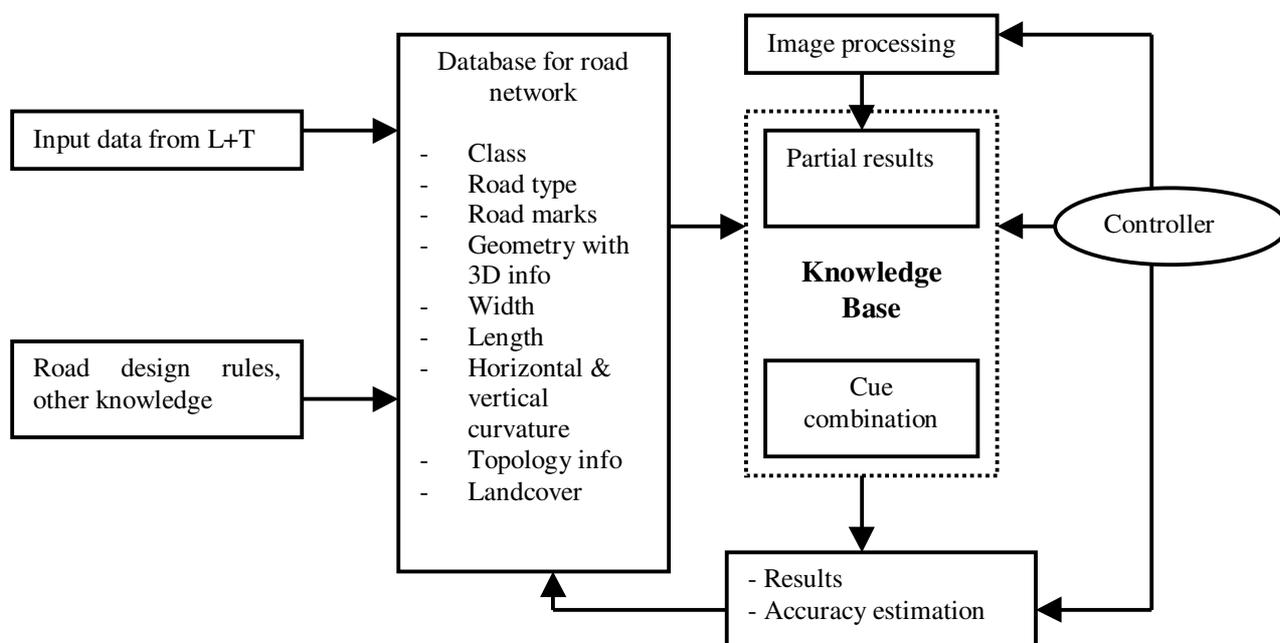


Figure 5. Strategy of road network extraction in ATOMI.

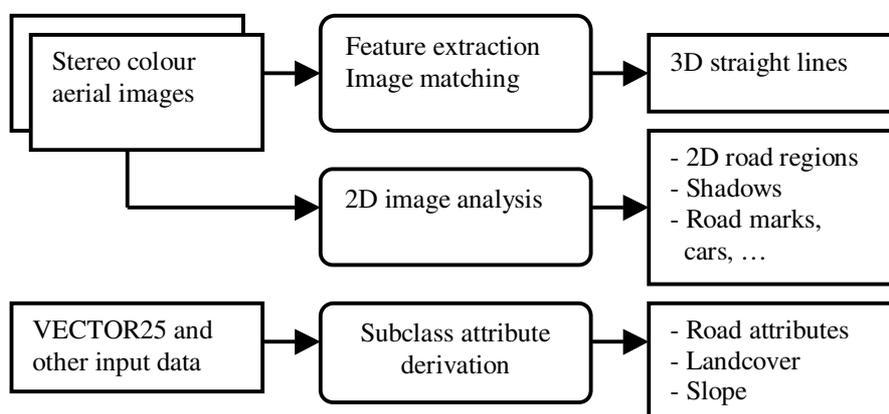


Figure 6. Details of image processing and derivation of subclass vector attributes.

3D edge generation is a crucial component of our procedure. We are interested in 3D straight lines because they are prominent in most man-made environments, and usually correspond to objects of interest in images, such as buildings and road segments. They can be detected in image data, and they provide a great deal of information about the structure of the scene. Additionally, since edge features have more support than point features, they can be localised more accurately. The 3D information of straight lines is determined from the correspondences of line segments between two images. Edges are derived by the Canny operator and subsequent straight line fit (Henricsson, 1996). The developed method exploits rich line attributes and line geometrical structure information. The rich line attributes include the geometrical description of the line (position, length, orientation) and the photometric information in the regions left and right of the line (flanking regions) using the Lab colour space. With known orientation parameters, the epipolar constraint can be employed to reduce the search space. The comparison with each candidate edge is then made only in the common overlap length, i.e. ignoring length differences and shifts between edge segments. For each pair of lines, which satisfy the epipolar constraints above, their rich attributes are used to compute a similarity score. The similarity score is a weighted combination of various criteria. All the scores are from 0 to 1, and the total similarity score is the average of all scores. The similarity score computation starts from the longer lines, while the very short ones (< 5 pixels) are ignored. After performing similarity measurement computation, we construct a matching pool and attach a similarity score to each line pair. However, one still has problems to determine the best matches. In addition, matching using a very local comparison of line attributes does not necessarily give results consistent in the neighbourhood. Locally consistent matching is achieved through structural matching of neighbouring edges with probability relaxation, whereby the similarity scores serve as prior information. Structural matching is conducted bidirectionally from left to right and right to left. The next step is a combined 2D and 3D grouping of straight segments. Thereby, information in one space helps bridging gaps and combining segments in the other space. Thus, small gaps are bridged, edges broken in multiple straight segments are combined, matched segments of different length are extended. The final 3D position is computed from the original edge pixels and not the fitted straight lines. A 3D straight line (or polyline) is then fitted to the 3-D points.

The proposed method for straight line matching is implemented and experiments have been performed on a number of areas extracted from aerial images. The test areas cover different terrain and landcover, including rural areas, suburban, urban, and hills. Figures 7-9 show an example. The line extraction process resulted in 985 and 971 straight lines in the left and right images respectively (see Fig. 8). Only 789 and 809 lines in the left and right images are longer than 5 pixels. 460 matches are found, of which only 5 are wrong matches. The matching result is shown in Fig. 9.



Figure 6. The test image pair.

Figure 7. Extracted straight lines.

Figure 8. The matching results.

Besides the work on straight line matching and 3D line generation, we completed a multispectral image classification method to find road regions. Guided by the initial knowledge base, we excluded the lines outside the road buffer area (this area is defined using the road centerlines of VECTOR25 and their estimated maximum error). By combining the 2D lines with the classification result, a relation with the road region (in, outside, at the border) is attached to each line. Lines with a slope difference to the slope from the known local DHM25 larger than a certain value are excluded.

6 OUTLOOK

We presented a new scheme for road and building reconstruction from aerial images. The proposed idea uses as much information as possible to increase success rate and reliability of the results. The project still needs significant work to be successfully completed. The most difficult part, the combination of all available information, disambiguation of conflicts and derivation of reliable quality criteria, lies ahead. Use of more than two images will be made with our test

dataset, especially for roads in urban areas that are heavily occluded. Regarding roads, the extraction of roadsides by fusion of various 2D and 3D information extracted from images and knowledge from a road database, and modelling roads of different classes in various terrain relief and landcover will be a major issue. Cues like cars on road and road marks will be extracted to confirm the reconstruction results. Building extraction in dense urban centres will also be investigated. An additional difficulty in this case, stems from the fact that the VECTOR25 data describe in this case the outline of all buildings in a block. Finally, a metric for quality estimation will be developed, and the results will be evaluated with manually extracted ground truth reference data.

REFERENCES

- Aas, K., Solberg, A., Koren, H. and Solberg, R., 1997. Semi-automatic revision of forest maps combining spectral, textural, laser altimeter and GIS data. Proc. 3rd Int. Airborne Rem. Sens. Conf. and Exhib., Copenhagen, Denmark, pp. 405-411.
- Aero-sensing Radarsysteme, 2000. <http://www.op.dlr.de/aerosensing> (accessed April 18, 2000).
- Axelsson, P., 1999. Processing of laser scanner data - algorithms and applications. ISPRS J. of Photogr. and Rem. Sens., 54(2-3), pp. 138-147.
- Baillard, C., Schmid, C., Zisserman, A., Fitzgibbon, A., 1999. Automatic line matching and 3D reconstruction of buildings from multiple views. IAPRS, Vol. 32, Part 3-2W5, pp. 69-80.
- Bordes, G., Giraudon, G., Jamet, O., 1997. Road modeling based on a cartographic database for aerial image interpretation. In: Semantic Modeling for the Acquisition of Topographic Information from Images and Maps, W. Förstner and L. Plümer (Eds.), Birkhäuser Verlag, Basel, pp. 123-139.
- Burkhart, G.R., Bergen, Z., Carande, R., Hensley, W., Bickel, D., Fellerhoff, J.R., 1996. Elevation correction and building extraction from interferometric SAR imagery. Proc. IGARSS, Vol. I, pp. 659-661.
- Chellappa, R., Zheng, Q., Davis, L.S., Lin, C.L., Zhang, X., Rodriguez, C., Rosenfeld, A., Moore, T., 1994. Site-model-based monitoring of aerial images. Proc. DARPA Workshop on Image Understanding, pp. 295-318.
- Chilton, T., Jaafar, J., Priestnall, G., 1999. The use of laser scanner data for the extraction of building roof detail using standard elevation derived parameters. IAPRS, Vol. 32, Part 3W14, pp. 137-143.
- de Gunst, M., 1996. Knowledge-based interpretation of aerial images for updating road maps. Ph.D. thesis, Delft Univ. of Technology, Faculty of Geodetic Eng., Netherlands Geodetic Commission, New Series, Vol. 44, 184 pp.
- Förstner, W., Plümer L. (Eds.), 1997. Semantic Modeling for the Acquisition of Topographic Information from Images and Maps. Birkhäuser Verlag, Basel.
- Frischknecht, S., Kanani, E., 1997. Possibilities to extract and structure objects from scanned topographic maps for use in GIS. Proc. of 18th Int. Cartographic Conf., Stockholm, Sweden, pp. 1022-1029.
- Gamba, P., Houshmand, B., 1999. Integration of high resolution multispectral imagery with LIDAR and IFSAR data for urban analysis applications. IAPRS, Vol. 32, Part 3W14, pp. 111-117.
- Große, S., 1999. Knowledge based interpretation of multisensor and multitemporal remote sensing images. IAPRS, Vol. 32, Part 7-4-3 W6, pp. 130-138.
- Gruen, A., Kübler, O., Agouris, P. (Eds.), 1995. Automatic Extraction of Man-Made Objects from Aerial and Space Images, Birkhäuser Verlag, Basel.
- Gruen, A., Baltsavias, E.P., Henricsson, O. (Eds.), 1997. Automatic Extraction of Man-Made Objects from Aerial and Space Images (II), Birkhäuser Verlag, Basel.
- Gruen, A., Li, H., 1997. Semi-Automatic Linear Feature Extraction by Dynamic Programming and LSB-Snakes. PERS, 63(8), pp. 985-995.
- Gruen, A., Wang, X., 1998. CC-Modeler: a topology generator for 3-D city models. ISPRS J. of Photogr. and Rem. Sens., (53)5, pp. 286-295.
- Gülch, E., Müller, H., Läbe, T., 1999. Integration of Automatic Processes Into Semi-Automatic Building Extraction. IAPRS, Vol. 32, Part 3-2W5, pp. 177-186.
- Haala, N., Brenner C., 1998. 3D urban GIS from laser altimeter and 2D map data. IAPRS, Vol. 32, Part 3/1, pp. 339-346.
- Haala, N., Brenner C., 1999. Extraction of buildings and trees in urban environments. ISPRS J. of Photogr. and Rem. Sens., 54(2-3), pp. 130-137.

- Henderson, F.M., Xia, Z.G., 1997. SAR applications in human settlement detection, population estimation and urban land use pattern analysis: a status report. *IEEE Trans. on Geoscience and Rem. Sens.*, 35(1), pp. 79-85.
- Henricsson O., 1996. Analysis of Image Structure using Color Attributes and Similarity Relations. Ph.D. Thesis, Report No. 59, Institute of Geodesy and Photogrammetry, ETH Zurich.
- Henricsson, O., Bignone, F., Willuhn, W., Ade, F., Kübler, O., Baltsavias, E., Mason, S., Gruen, A., 1996: Project AMOBE: Strategies, Current Status and Future Work. *IAPRS*, Vol. 31, Part B3, pp. 321 - 330.
- Huang, X., Jensen, J.R., 1997. A machine-learning approach to automated knowledge-base building for remote sensing image analysis with GIS data. *PERS*, 63(10), pp. 1185-1194.
- Hug, Ch., Wehr, A., 1997. Detecting and identifying topographic objects in imaging laser altimetry data. *IAPRS*, Vol. 32, Part 3-4W2, pp. 19-26.
- Janssen, L.L., Jaarsma, M.N., van der Linden, E.T., 1990. Integrating topographic data with remote sensing for land-cover classification. *PERS*, 56(11), pp. 1503-1506.
- Koch, H., Pakzad, K., Tönjes, R., 1997. Knowledge based interpretation of aerial images and maps using a digital landscape model as partial interpretation. In: *Semantic Modeling for the Acquisition of Topographic Information from Images and Maps*, W. Förstner and L. Plümer (Eds.), Birkhäuser Verlag, Basel, pp. 3-19.
- Kunz, D., 1999. Investigation of synergy effects between satellite imagery and digital topographic databases by using integrated knowledge processing. *IAPRS*, Vol. 32, Part 7-4-3 W6, pp. 144-151.
- Lammi, J., 1998. Geometric modelling of buildings based on incremental feature extractions and multiple representations. *IAPRS*, Vol. 32, Part 3/1, pp. 355-359.
- Lemmens, M.J.P.M., Deijkers, H., Looman, P.A.M., 1997. Building detection by fusing airborne laser-altimeter DEMs and 2D digital maps. *IAPRS*, Vol. 32, Part 3-4W2, pp. 42-49.
- Liedtke, C.E., Bückner, J., Grau, O., Growe, S., Tönjes, R., 1997. AIDA: A system for the knowledge based representation of remote sensing data. *Proc. 3rd Int. Airborne Rem. Sens. Conf. And Exhib.*, Copenhagen, Denmark, pp. 313-320.
- Maas, H.G., Vosselman, G., 1999. Two algorithms for extracting building models from raw laser altimetry data. *ISPRS J. of Photogr. and Rem. Sens.*, 54(2-3), pp. 153-163.
- Maître, H., Bloch, I., Moissinac, H., Gouinaud, C., 1995. Cooperative use of aerial images and maps for the interpretation of urban scenes. In: *Automatic Extraction of Man-Made Objects from Aerial and Space Images*, A. Gruen, O. Kübler and P. Agouris (Eds.), Birkhäuser Verlag, Basel, pp. 297-306.
- Matsuyama, T., Hwang, V.S.-S., 1990. *SIGMA: A knowledge-based aerial image understanding system*. Plenum Press, New York, 277 p.
- Mercer, J.B., Gill, M., 1998. Radar-derived DEMs for urban areas. *IAPRS*, Vol. 32, Part 4, pp. 382-388.
- Niederöst, M., 2000. Reliable Reconstruction of Buildings for Digital Map Revision. *IAPRS*, Vol. 33, (in Proc. of this Congress).
- Plietker, B., 1994. Semiautomatic revision of street objects in ATKIS database DLM 25/1. *IAPRS*, Vol. 30, Part 4, pp. 311-317.
- Plietker, B., 1997. Automatisierte Methoden zur ATKIS-Fortführung auf der Basis von digitalen Orthophotos. *Photogrammetric Week '97*, Wichmann, D. Fritsch and D. Hobbie (Eds.), pp. 135-146.
- Prechtel, N., Bringman, O., 1998. Near-real-time road extraction from satellite images using vector reference data. *IAPRS*, Vol. 32, Part 2, pp. 229-234.
- Quint, F., 1997a. MOSES: A structural approach to aerial image understanding. In: *Automatic Extraction of Man-Made Objects from Aerial and Space Images (II)*, A. Gruen, E.P. Baltsavias and O. Henricsson (Eds.), Birkhäuser Verlag, Basel, pp. 323-332.
- Quint, F., 1997b. Kartengestützte Interpretation monokularer Luftbilder. Ph.D. dissertation, Deutsche Geodätische Kommission, Reihe C, No. 477.
- Quint, F., Sties, M., 1995. Map-based semantic modeling for the extraction of objects from aerial images. In: *Automatic Extraction of Man-Made Objects from Aerial and Space Images*, A. Gruen, O. Kübler and P. Agouris (Eds.), Birkhäuser Verlag, Basel, pp. 307-316.
- Pakzad, K., Bückner, J., Growe, S., 1999. Knowledge based moorland interpretation using a hybrid system for image analysis. *IAPRS*, Vol. 32, Part 3-2W5.

- Renouard, L., Lehmann, F., 1999. High resolution digital surface models and orthoimages for Telecom network planning. Photogrammetric Week '99, D. Fritsch and R. Spiller (Eds.), Wichmann Verlag, Heidelberg, pp. 241-246.
- Rieger, W., Kerschner, M., Reiter, T., Rottensteiner, F., 1999. Roads and buildings from laser scanner data within a forest enterprise. IAPRS, Vol. 32, Part 3W14, pp. 185-191.
- Roux, M., Maître, H., 1997. Three-dimensional description of dense urban areas using maps and aerial images. In: Automatic Extraction of Man-Made Objects from Aerial and Space Images (II), A. Gruen, E.P. Baltsavias and O. Henricsson (Eds.), Birkhäuser Verlag, Basel, pp. 311-322.
- Schilling, K.-J., Vögtle, Th., 1997. An approach for the extraction of settlement areas. In: Automatic Extraction of Man-Made Objects from Aerial and Space Images (II), A. Gruen, E.P. Baltsavias and O. Henricsson (Eds.), Birkhäuser Verlag, Basel, pp. 333-342.
- Solberg, A., Jain, A. K., Taxt, T., 1993. Fusion of multitemporal satellite images and GIS data for land-use classification. Proc. of 8th Scandinavian Conf. on Image Analysis, Tromsø, 25-28 May.
- Stengele, R., 1995. Kartographische Mustererkennung. Ph.D. dissertation, Report No. 54, Institute of Geodesy and Photogrammetry, ETH Zurich.
- Stilla, U., 1995. Map-aided structural analysis of aerial images. ISPRS J. of Photogr. and Rem. Sens., 50(4), pp. 3-10.
- Stilla, U., Jurkiewicz, K., 1999. Automatic reconstruction of roofs from maps and elevation data. IAPRS, Vol. 32, Part 7-4-3W6, pp. 139-143.
- Tönjes, R., 1997. 3D reconstruction of objects from aerial images using a GIS. IAPRS, Vol. 32, Part 3-2W3, pp. 140-147.
- Tönjes, R., Growe, S., 1998. Knowledge based road extraction from multisensor imagery. IAPRS, Vol. 32, Part 3/1, pp. 387-393.
- Tönjes, R., Growe, S., Bückner, J., Liedtke, C.E., 1999. Knowledge based interpretation of remote sensing images using semantic nets. PERS, 65(7), pp. 811-821.
- van Cleynenbreugel, J., Fierens, F., Suetens, P., Oosterlink, A., 1990. Delineating road structures on satellite imagery by a GIS-guided technique. PERS, 56(6), pp. 893-898.
- Vosselman, G., de Gunst, M., 1997. Updating road maps by contextual reasoning. In: Automatic Extraction of Man-Made Objects from Aerial and Space Images (II), A. Gruen, E.P. Baltsavias and O. Henricsson (Eds.), Birkhäuser Verlag, Basel, pp. 267-276.
- Vosselman, G., Veldhuis, H. 1999. Mapping by dragging and fitting of wire-frame models. PERS, 65(7), pp. 769-776.
- Walter, V., 1998. Automatic classification of remote sensing data for GIS database revision. IAPRS, Vol. 32, Part 4, pp. 641-648.
- Walter, V., 1999. Automated GIS data collection and update. Photogrammetric Week '99, D. Fritsch and R. Spiller (Eds.), Wichmann Verlag, Heidelberg, pp. 267-280.
- Walter, V., Fritsch, D., 1998. Automatic verification of GIS data using high resolution multispectral data. In : IAPRS, Vol. 32, Part 3/1, pp. 485-490.
- Zhang C., Baltsavias E.P., 2000. Knowledge-based image analysis for 3D edge extraction and road reconstruction. Proc. of 19th ISPRS Congress, Amsterdam, Netherlands, 16-23 July. IAPRS, Vol. 33 (in Proc. of this Congress).
- Zhang, Y., 1998. Detection of urban housing development using multisensor satellite data and maps. IAPRS, Vol. 32, Part 3/1, pp. 292-299.