AUTOMATIC ROAD EXTRACTION BY INTEGRATED ANALYSIS OF IMAGES AND GIS DATA

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ABSTRACT

Accurate 3D road network is a vital component of GIS for many applications, including traffic management, monitoring, city modeling, and visualization. This paper presents a practical system for automated 3D road network reconstruction by integrated processing of color image data and information from existing digital spatial databases. Starting from the existing database, the road attributes and the approximated road geometry are derived. Guided by this knowledge, various features including 3D straight edges, road regions, shadows, roadmarks and zebra crossings are extracted by the developed algorithms. The system then uses and fuses these features, existing information to generate and group road primitives to extract the roads. The key of the system is the use of knowledge as much as possible to increase success rate and reliability of the results, working in 2D images and 3D object space, and use of 2D and 3D interaction when needed. Another advantage of the developed system is that it can correctly and reliably handle problematic areas caused by shadows and occlusions. To complete the road network reconstruction, an efficient approach for road junction modeling has also been developed. The system was originally developed to process stereo images, but it has been modified to work also with orthoimages, thus making it applicable to sensors of unknown geometry. The system has been implemented as a stand-alone software package, and has been tested on a large number of images with different landscape. In this paper, various parts of the developed system are discussed, and the results of our system in the tests conducted independently by our project partner are presented together with the system performance evaluation.

INTRODUCTION

The extraction of roads from digital images has drawn considerable attention in the last few decades. This is increasingly stimulated by various existing and emerging applications requiring in particular up-to-date, accurate and sufficiently attributed road databases. The fact that most vendors of commercial photogrammetric, remote sensing and GI systems do not offer anything useful regarding automation of road extraction (not even practical semi-automatic methods) stresses the importance of this research topic. The existing approaches for road extraction cover a wide variety of strategies, using different resolution aerial or satellite images. A quite extensive overview of such approaches is given in Zhang (2003a). Semi-automatic schemes require human interaction to provide interactively some information to control the extraction. Roads are then extracted by profile matching (Vosselman and Knecht, 1995), cooperative algorithms (McKeown et al, 1988) and dynamic programming or LSB-Snakes (Grün and Li, 1997). Automatic methods usually extract reliable hypotheses for road segments through edge and line detection and then establish connections between road segments to form road networks (Wiedemann et al., 1998). Data from different sources is often useful (Price, 1999). Contextual information is taken into account to guide the extraction of roads (Heipke et al., 2000). Roads can be detected in multi-resolution images (Baumgartner and Hinz, 2000), while Hinz and Baumgartner (2003) use context and scale-dependent models for extraction of urban roads in large-scale images.

Several applications use map information (Gerke et al., 2003). The map data is used either as approximation to start tracking or optimization process by Snakes (Bordes et al., 1997; Agouris et al., 2001), or to search for new roads (Vosselman and de Gunst, 1997). The road maps can be updated by map-image matching (Klang, 1998). The existing approaches show individually that the use of road models and varying strategies for different types of scenes are promising. However, all the methods are based on relatively simplistic road models, and most of them make only insufficient use of a priori information, thus they are very sensitive to disturbances like cars, shadows or occlusions, and do not always provide good quality results. Furthermore, most approaches work in single 2D images, thus neglecting valuable information inherent in 3D processing.

In this paper, we present a knowledge-based system for automatic extraction of 3D roads from stereo aerial images which integrates processing of color image data and existing digital spatial databases. The system has been developed within the project ATOMI (Automated reconstruction of Topographic Objects from aerial images using vectorized Map Information), in cooperation with the Swiss Federal Office of Topography (swisstopo), with aims to improve road centerlines from digitized 1:25,000 topographic maps by fitting them to the real landscape, improving the planimetric accuracy to 1m and providing height information with 1-2m accuracy (Eidenbenz et al., 2000). The usual input data include 1:16,000 scale color imagery, with 30cm focal length, and 60%/20% forward/side overlap, scanned with 14 microns at a Zeiss SCAI. The other input data include: a nationwide DTM with 25m grid spacing and accuracy of 2-3/5-7m in lowland/Alps, the vectorized map data (VEC25) of 1:25,000 scale, and the raster map with its 6 different layers. The VEC25 data have a RMS error of ca. 5-7.5m and a maximum one of ca. 12.5m, including generalization effects. They are topologically correct, but due to their partly automated extraction from maps, some errors exist. In addition, DSM data in the working area with 2m grid spacing was generated from stereo images using MATCH-T of INPHO.

GENERAL STRATEGY

The developed system makes full use of available information about the scene and contains a set of image analysis tools. The management of different information and the selection of image analysis tools are controlled by a knowledge-based system. In this section, a brief description of our strategy is given. We refer to Zhang (2003a) and Zhang (2003b) for more details. The initial knowledge base is established by the information extracted from the existing spatial data and road design rules. This information is formed in object-oriented multiple object layers, i.e. roads are divided into various subclasses according to road type, land cover and terrain relief. It provides a global description of road network topology, and the local geometry for a road subclass. Therefore, we avoid developing a general road model; instead a specific model can be assigned to each road. This model provides the initial 2D location of a road in the scene, as well as road attributes, such as road class, presence of roadmarks, and possible geometry. A road is processed with an appropriate method corresponding to its model, certain features and cues are extracted from images, and roads are derived by a proper combination of cues. The knowledge base is then automatically updated and refined using information gained from previous extraction of roads. The processing proceeds from the easiest subclasses to the most difficult ones. Since neither 2D nor 3D procedures alone are sufficient to solve the problem of road extraction, we make the transition from 2D image space to 3D object space as early as possible, and extract the road network with the mutual interaction between features of these spaces.

CUE EXTRACTION

When a road from VEC25 is selected, the system focuses on the image regions around the road, defined using the position of the road and the maximal error of VEC25. Then, according to the road attributes a set of image processing tools is activated to extract features and cues. 3D straight edge generation is a crucial component of our procedure because the road sides are among them. The 3D information of straight edges is determined from the correspondences of edge segments between stereo images. An image classification method is implemented to find road regions. With the DSM and DTM data, the above-ground objects and ground objects are separated. We also exploit additional cues such as roadmarks to support road extraction.

3D Straight Edge Extraction

The edges are extracted by the Canny operator in stereo images. For each edge, the edge attributes are computed, including the geometrical description of the edge and the photometrical information in the flanking regions of the edge. The epipolar constraint is applied to reduce the search space. We then compute a similarity measure for an edge pair by comparing the edge attributes. The similarity measure is then used as a prior information in structural matching with probability relaxation, through which the locally consistent matching is achieved. The method seeks the probability that an edge in one image matches an edge in the other image, using the geometrical structure information and photometric information of the neighbouring image edges. The matching approach has a high success rate and most importantly is very reliable. We refer to Zhang and Baltsavias (2000) for the detailed matching strategy and qualitative performance evaluation. The matched edges are then transformed to object space by finding the corresponding pixels within each matched edge pair (Zhang and Baltsavias, 2002). Finally, 3D straight edge segments are fitted to the 3D edge pixels.

Image Classification for Road Region Detection

We implemented the ISODATA algorithm to classify the color images and separate road regions from other objects. The success of image classification also depends on the input data. The original RGB color image is transformed into different color spaces and is also used to compute several artificial bands/indices to enhance features such as vegetation and shadows so that they are more isolated in feature space. The following 3 bands are selected for image classification: (1) the first component of principal component transformed image, (2) a band calculated with R and G bands in RGB space as (G-R)/(G+R), (3) S band from HSI color space. We then determine 5 classes corresponding to road regions, green objects, shadow areas, dark roofs and red roofs.

DSM and DTM Analysis

The DTM or DSM has been used in our system to reduce search space for straight edge matching. They are also used to verify if a 3D straight edge or a region is on the ground. Because a DSM ideally models the man-made objects as well as the terrain, subtracting the DTM from DSM results in the so-called normalized DSM (nDSM) which enables the separation of above-ground objects (buildings and trees) and ground objects (roads, etc.). Since the DTM data in our project is not very accurate, subtracting the DSM from this DTM may lead to wrong results. Thus, we extract above-ground objects and the nDSM from the DSM data only, therefore avoiding introducing errors from the DTM. This is realized by a Multiple Height Bin (MHB) method presented in Baltsavias et al. (1995). The method is simple, fast and very effective. Through the combination of the nDSM information with image classification data, our system creates redundancy to confirm the existence of roads. In addition, it can partly compensate missing or wrong information in the classification data.

Roadmark and Zebra Crossing Extraction

Roadmarks and zebra crossings are good indications of the existence of main roads and roads in urban areas. Both of them have distinct color (usually white or yellow). In high-resolution images, such as the ones used in our project, roadmarks are white thin lines with a certain width. The zebra crossings are shown as yellow strips. Usually roadmarks give the road direction and often the road centerline, while the zebra crossings define the local road width. Thus, they can be used to guide the road extraction process or verify the extraction results. In addition, in many cases the correct road centerlines can be even derived directly from present roadmarks and/or zebra crossings. This is especially useful when the road sides are occluded or not well-defined, such as in cities or city centers.

The roadmarks are detected as white straight lines using an image line model in which the shape of an image line is presented as a second order polynomial (Zhang, 2003a). The extracted straight lines are then transformed into object space by our developed structural matching method. Only those that are on the ground (as defined by nDSM), belonging to the road region (as determined by the classification) and in the buffer defined by VEC25 are kept as detected roadmarks. Zebra crossings are composed of several thin stripes. Using color information, the image is first segmented. Morphological closing is applied to bridge the gaps between zebra stripes. We then obtain several clusters by connected labeling. Only the clusters with a certain size are kept, while the small ones are discarded. Then, the shape of the cluster is analyzed. The rectangle-like clusters are selected as zebra crossings. The center, the short and long axes of the detected zebra crossings are computed using spatial moments.

3D ROAD RECONSTRUCTION

With the extracted features and cues, our next step is to combine them to extract the road. Firstly, irrelevant edges are removed. 3D parallel overlapping edges are then searched for, and are evaluated to find possible road sides. Due to occlusions or shadows, a road and its sides may be totally or partially invisible in images. The road segments with only one side visible in one or two images in the occluded/shadowed areas are inferred and reconstructed. In addition, gaps, where the road sides are totally invisible, are bridged. Finally, the road is reconstructed by finding an optimal path among the road segment candidates that maximizes a merit function. Highways, first class roads and most second class roads are also extracted using the detected roadmarks and the zebra crossings. With the extracted roads, the road junctions are reconstructed and modelled. The main procedures are described below. More details on all above procedures are given in Zhang (2003a).

Finding 3D Parallel Road Sides

The system checks the extracted edges to find 3D parallel edges. Only edges located in the buffer defined by the VEC25, having a similar orientation to the VEC25 segments and a certain slope are further processed. Edges above the ground are removed by checking with the nDSM. Two edges are considered as parallel if they have similar orientation in 3D space. The edges of a pair must overlap in the direction along the edges, and the distance between them must be within a certain range determined by the road class defined in the VEC25. In addition, the heights of the two edge segments should be similar. The found 3D parallel edges are projected onto the images and evaluated using multiple knowledge. The region between the projected edges must belong to the class road as determined by the image classification. If roadmarks are presented on this road, the extracted roadmarks are used to confirm that the edge pair corresponds to correct road sides. The found 3D parallel edges have high probability of belonging to a road; they are called Possible Road Sides that are Parallel (PRSP). Thus, each PRSP is geometrically described by a pair of 3D straight edges and its corresponding 2D edges, and holds a set of attributes.

Reconstruction of Missing Road Sides

Not all 3D road segments can be obtained from the procedures described above. The absence of 3D road sides can be caused by shadows, occlusions, or road sides do not actually exist, e.g. in the area where a parking lot is situated next to the road. Depending on the relations between the road segments and the neighbouring objects, sun angle, viewing direction, existence of moving cars on the road etc., there are various types of missing road sides in images. We have made an investigation and classified them into 11 types. Each type is then treated, and the missing road sides are inferred and validated by a specific procedure (Zhang, 2003a). Based on the type of the missing road sides, corresponding types of road segment candidates (RSCs) are obtained. They are then evaluated using the knowledge obtained from the cues. Common reliability measures for all RSCs are evaluated using the results from the image classification and the nDSM. In addition, specific reliability measures for each type of RSC are also computed using the geometric relations between the RSC and its adjacent PRSPs. We refer to Zhang (2003a) for the detailed procedures of RSC evaluation.

Closing of Gap

A gap between neighbouring PRSPs that belongs to a road represents a road part where no road side is visible in the images. In our system, it is bridged either by directly linking the neighbouring PRSPs or by adapting the shape of the VEC25 road corresponding to the gap area. That is, the vertices of the VEC25 road in the gap area are shifted to close the gap, based on the coordinate differences between the end points of the PRSPs and their corresponding points on the VEC25 road. Linking the adjacent PRSPs to close gaps is efficient on straight roads with short gap length, while using the shape of VEC25 road might be more useful for long and curved occlusion areas. We determine the solution for gap bridging in an evaluation process using various knowledge, e.g. the shape of the solution for the gap should approximately comply with that of the VEC25 road; it should be either a road region or a shadow or shadow mixed with road region; or roadmarks are extracted within the hypothesised road area. Based on the evaluation, we compute a measure for the gap hypothesis, s_{gap} The range of values for s_{gap} is [0,1], with decreasing value for long and inconsistent gaps.

Road Segment Linking for 3D Road Reconstruction

With the extracted PRSPs, the road is reconstructed by linking the PRSPs belonging to a road. The goal of linking road segments is twofold. First, this implies that PRSPs belonging to a road should be selected and connected with the gaps bridged by the linking algorithm. Secondly, this also implies that PRSPs not belonging to a road should be rejected. Therefore, the algorithm must be very selective in which PRSP it adds to a road. The linking function in our system is defined as

$$\sum l_i \cdot s_i + l_{gap} \cdot s_{gap} + l_j \cdot s_j \tag{1}$$

where, i and j are adjacent PRSPs, l_i and l_j are their lengths, s_i and s_j are their reliability measures. l_{gap} is the gap length between i and j, and s_{gap} is the gap evaluation measure. The function takes high values for long curves with a shape similar to the VEC25 road. The linking problem can then be solved by finding a subset among all PRSPs that maximizes the linking function. This can be achieved using dynamic programming (Grün and Li, 1997).

Higher class roads are also extracted using the detected roadmarks and zebra crossings. The roadmarks are linked using a similar method as described in the previous paragraph. This procedure increases the effectiveness and reliability of our system. In complex areas, such as in city centers, the road sides are generally occluded very much, while sometimes they are not defined. However, the road centerlines are successfully extracted by the system using roadmarks. In rural and suburban areas, the extracted road using roadmarks is used by the system to verify the extraction results using 3D parallel edges.

Road Junction Generation and Modeling

Road junctions are important features of the road network. However, it is even more difficult to model and extract road junctions from images than road segments. This might be one of the reasons that this issue has been rarely touched in past research. In our system, we reconstruct junctions through intersecting the extracted roads guided by the topology of the VEC25 data, and further model the junctions with road class information and the shape of the VEC25. During the process, each road is assigned a weight corresponding to the evaluation value of the road segment in the junction area. In addition, an angular constraint is applied forcing the angle of the two reconstructed roads at the reconstructed junction point similar to that defined by the corresponding VEC25 roads at the VEC25 junction point. Furthermore, in the angular constraint higher priority is given to higher class roads or continuous roads. In such formulation, the junction point is correctly located, while the shape of the roads at the junction point is well formed: complying with the reality and following the road design rules.

With the extracted roads and road junctions, the road network is obtained. The results inherit other attributes from the VEC25 data with the road lengths updated, and road widths appended. The number of lanes can be inferred from the known road width and also possibly roadmarks. The 3D information permits the derivation of other useful attributes like horizontal and vertical curvatures and road slope.

Performance Evaluation

We introduce two types of measure for self-diagnosis of the extraction results: an overall quality measure for the whole road, and measures for the road segments. If a result does not pass the overall quality test, a further test is conducted to find in which segments the errors occur. The overall quality of the extraction result can be obtained from the following criteria:

- the lengths of the extraction result and the VEC25 road should be similar
- the shape difference between the extraction and the VEC25 road should be small
- total length of PRSPs should cover a large part of the extraction result

We also define an internal quality measure for each road segment using the shape similarity measure between the segment and the corresponding VEC25 road, and the information in the classification result and the nDSM in the segment area (Zhang, 2003b). For higher class roads, the assessment of the reliability of the extraction results is also conducted through comparison of the results by using parallel edges and roadmarks.

External evaluation is done by comparing the extracted results with precise reference data. The quality measures aim at assessing completeness and correctness as well as geometrical accuracy (Heipke et al., 1998; Zhang, 2003b). Additional measures have been defined, e.g. to evaluate the shape quality, but have not been used in the test results presented here.

RESULTS

The described system has been implemented as a stand-alone software package with a graphic user interface running both on UNIX SGI and PC Windows XP. The system imports color stereo or ortho-imagery, the existing road database and other input data, and outputs the extracted roads in 3D Shapefile format that is readily imported by existing GIS software. Other data formats can be easily accommodated. The system has been tested using more than 20 models in various landscapes. Some reports of the system performance can be found in Zhang and Baltsavias (2002) and Zhang (2003b). A benchmark test has been conducted independently by our project partner using new flight imagery, in the test site Thun, Switzerland. The terrain height ranges from 550 m to 2200 m. Almost all road types in Switzerland can be found in this area. The images were acquired in October 2001, and the image data have the same specifications as described in Section 1. During the test, our system is only applied to extract roads in rural areas, while roads in urban and forest areas are not processed. Fig. 1 presents a portion of 3D road extraction and road network generation (only the left image is shown). The landscape of Fig. 1 includes open rural, forest areas and small settlements.

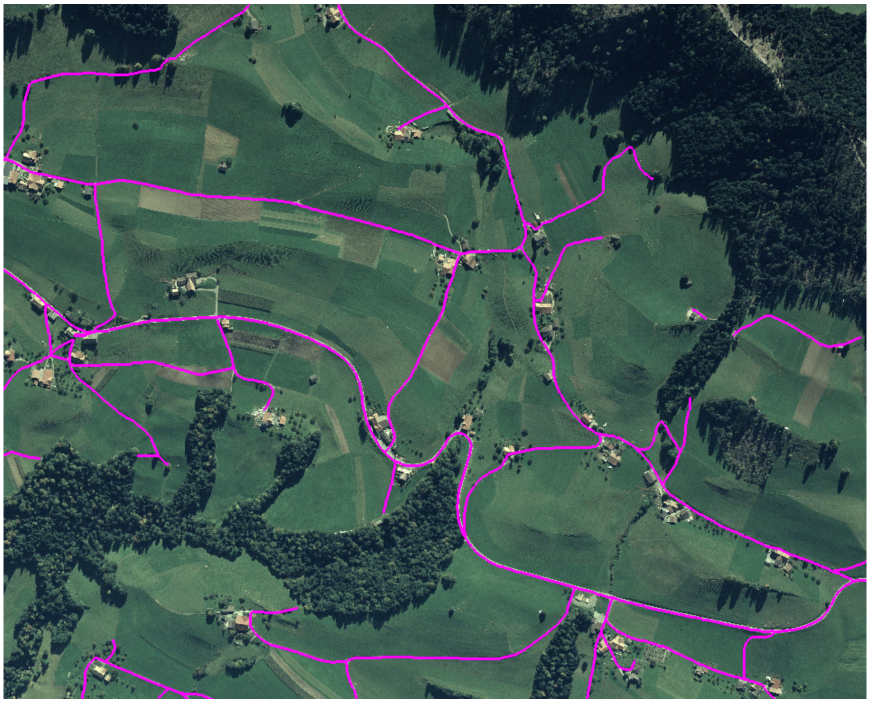

Figure 1. Extracted 3D roads and road network in test site Thun, Switzerland.

The details of automatic 3D road extraction and junction generation in rural areas with varying complexity are presented in Fig. 2, where the VEC25 roads are shown in yellow lines and the extracted roads in pink lines. Note that the road junctions are also well extracted and modeled.

Figure 2. Details of road extraction and junction generation with varying complexity in test sites in Switzerland. The extracted roads are shown in pink lines and the VEC25 roads in yellow lines.

Table 1 summarises the external evaluation of the extraction results in Fig. 1 using the reference data measured by swisstopo at an analytical plotter. It can be seen that our system achieves very good results. The completeness and correctness are very high. The accuracy of the extracted road network is about 0.5 m both in planimetry and height, fulfilling the accuracy requirements of the project ATOMI.

Table 1. Quality measures for the test dataset in Fig.1

Quality Measures		
Completeness		94.2%
Correctness		96.9%
Length of reference (km)		12.4
Length of extraction (km)		11.69
RMS (m)	dx	0.40
	dy	0.33
	dz	0.58

A higher completeness has been achieved by our partner when spring photography is used. This is because of less tree occlusions. Even some roads along forest borders can be extracted in spring images. In addition, some roads in fields, invisible in summer images, are visible in spring images and are extracted, thus further contributing to a higher completeness of the extracted road network.

Figure 3. A Seasonal road only partially visible in summer image (left) is extracted in spring image (right).

We also tested our system on unknown data provided by the National Geographic Institute, Belgium. Although the images are black and white with quite poor radiometric quality, and no DSM is available, the performance of our system is also quite good in flat open rural areas. Comparison of the results with the manually measured reference data for ca. 13 km roads reveals that the achieved completeness and correctness are 97.6% and 98.1% respectively (Zhang and Baltsavias, 2002).

The system has been modified to work even with orthoimages, whereby the 3D information is not extracted by image matching, but by overlaying the 2D information on the DSM or DTM. Extensive tests conducted by our Swiss project partner using various resolution orthoimages (0.20 m ~ 0.60 m) have shown that the results are quite similar to that from the stereo imagery, and that an increase of the pixel size leads to a proportionally much smaller deterioration of the geometric accuracy of the extracted roads. With this development, the Dutch Ministry of Transport, Public Works and Water Management (MTPWWM) awarded to us, after an evaluation of various research systems, a project for a feasibility study of semi-automated updating of the Dutch road database, using color orthoimages of 0.5 m pixel size from aerial images of 1:25,000 scale with 15 cm focal length. The study site is situated near the city of Weert in the province Limburg (in the south of the Netherlands), covering an area of 12 * 12 sq. km. The landuse changes gradually from open rural to urban, with the complexity of the scenes increasing correspondingly. The images were taken in June, 2000. The images do not have good quality; they are too green and noisy. In many cases the roads show very poor contrast with surroundings. The image edges are poorly defined; also color shifts between bands are observed. In addition, trees at road sides usually occlude roads very much in these summer images; some roads are even totally occluded. We also observed that the roadmarks on roads are very weakly represented in such images. The old road databases are created by digitizing 1:10,000 topographic maps, with an RMS error of about 10 m. The database allows distinguishing national roads and a small part of the provincial roads in the Netherlands, and provides the number of lanes for them. The other roads are in a single class. There are no clues that can be used to infer the approximate road width. Available height data are from laser scanning (raw and filtered heights). Both datasets have points regularly distributed with a 5m x 5m spacing. During the test, our system is only applied in open rural areas. Fig. 4 shows a portion of the test results. The roads in rural areas are correctly and reliably extracted by our system. In Fig. 5, the details of road extraction and junction generation for this dataset are presented in several examples.

Reference data for the Dutch dataset is not available at moment. The accuracy of the extraction result cannot be accessed. In each test image we computed the ratio of the length of the extracted roads to the length of rural roads in the existing database (the total length of the rural roads in the old database is ca. 500 km). The ratio values range from 80% to 92%, depending on the complexity of the scene. Generally, the performance is worse compared to the performance on the Swiss dataset. This is mainly caused by: (1) the poor image quality, (2) insufficiently road information in the existing road database, especially the lack of the road classes or road width, (3) the images are taken in summer, many roads are occluded by trees, (4) the worse spatial resolution of 0.5m compared to 0.22m of the Swiss data.

Figure 4. Extracted 3D roads and road network in the test site in the Netherlands superimposed on image as pink lines.

Figure 5. Details of road extraction and junction generation in the Netherlands dataset.
The extracted roads are shown in pink lines and the outdated roads in yellow lines.

Before the system was put into production, it has undergone extensive test by our project partner, on areas with diverse terrain relief and landcover types using difference resolutions stereo and orthoimages. Tests have been also performed using ADS40, IKONOS and Quickbird data. The performance evaluation of the system using different sensor data in two varying test sites has been reported in Baltsavias et al. (2004). The evaluation shows that the road networks in rural areas can be reconstructed by the develop system using aerial orthoimages with maximum pixel size of ca. 50-60cm with a completeness and correctness of 90%-95% and an accuracy of 0.4-0.7m. This was further confirmed in an extensive test with around 10,000 km of roads using 50cm resolution orthoimage. Almost all roads in rural areas were correctly extracted using visual check. The processing speed is sufficient for operational production. roads in an average road density 1:25,000 map sheet covering 210 km^2 can be extracted in 3-4 hours on a Dell PC with Pentium 4, 2GHz CPU and 2GB RAM running Windows XP. Thus, using this not up-to-date computer configuration, all 1:25,000 map sheets of Switzerland could be processed in 36 days on a single PC.

DISCUSSION AND CONCLUSION

In this paper, we have presented a practical automated system for road extraction from stereo and ortho-images focusing on rural areas. The roads should have a minimum width of about 3 pixels in order that edges on both road sides are extracted. The system has several advantages over other approaches. It uses existing knowledge, image context, rules and models to restrict the search space, treats each road subclass differently, checks the plausibility of multiple possible hypotheses, therefore provides reliable results. The system contains a set of data processing tools to extract various cues about road existence, and fuses multiple cues and existing information sources. This fusion provides not only complementary information, but also redundant one to account for errors and incomplete partial results. Working on stereo images, the system makes an early transition from 2D image space to 3D object space. Road hypotheses are generated directly in 3D object space. This not only enables us to apply more geometric criteria to generate hypotheses, but also largely reduces the search space, and speeds up the process. The hypotheses are evaluated in images using accumulated knowledge information. Whenever 3D features are incomplete or entirely missing, 2D information from stereo images is used to infer the missing features. By incorporating multiple knowledge, the problematic areas caused by shadows, occlusions etc. can be often handled. Based on the extracted roads, the road junctions are generated and modeled, thus the system provides an up-to-date and complete road network for practical uses. We also present in this paper the results of road extraction in benchmark tests conducted independently by our project partner. The quantitative analysis using accurate reference data is also presented. The comparison of the reconstructed roads with such data shows that more than 94% of the roads in rural areas are correctly and reliably extracted by the developed system, and the achieved accuracy of the road centerlines is about 0.5 m both in planimetry and height, fulfilling the requirements of the project ATOMI. The system can also work with black and white images and no use of DSM without significant performance reduction (as the tests in Belgium have shown). We also showed that a higher completeness can be achieved if spring photography is used. An even better performance can be expected with the increasingly possible use of better quality DTMs and DSMs (e.g. from airborne laser scanning) and a near-infrared channel, which is available in many new digital photogrammetric cameras and high-resolution satellites.

The system can also process orthoimages. The extensive tests at the swisstopo in rural areas have shown that the performance is quite similar. We have presented the results in the study site of the Netherlands, with the dataset provided by MTPWWM, the Netherlands. Using a visual check, most of the roads in rural areas are extracted. The extraction results are quite good and reliable. There are only very few errors in the extraction results. Better results can be expected by using good quality images. Use of new digital cameras, e.g. ADS40 developed by Leica Geosystems, providing near infrared information would be an extra plus. The tests with ADS40 imagery at the swisstopo have shown that the road extraction results are similar (Baltsavias et al., 2004), however with larger pixel size and no use of the infrared channel. Use of digital photogrammetric cameras may prove to be advantageous for road extraction, on top of other advantages like faster data acquisition, avoidance of errors during scanning etc.

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